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**ANALYTICAL MODEL DESIGNED TO PREDICT THE
PROBABILITY OF EXPLOSION PROPAGATION BETWEEN
ADJOINING SINGLE AND GROUPED PROJECTILES**

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report contains the information for the development of a model to predict the probability of explosion propagation between adjoining explosive items; namely, high explosive projectiles. The development of this model is based on the sensitivity of an encased charge to primary fragment impact. The original work done under contract to Arthur D. Little, Inc., was extended to provide a method of predicting the effectiveness of shielding on (cont)		

20. ABSTRACT (cont)

projectile spacing requirements and also to predict the probability of detonation at a higher confidence level. The potential practical use of the model is judged to be adequate to warrant further investigation. When used in a generalized way, the model can be a valuable tool in the design and layout of facilities for the manufacture and storage of explosive items.

SUMMARY

This report describes a model to predict the probability of explosion propagation between adjoining explosive items. The model was first developed by Picatinny Arsenal under contract to Arthur D. Little, Inc., of Cambridge, Massachusetts. However, the reliability of that model was lower than the desired level. After certain modifications had been made, the model was improved to predict probabilities at 90 to 95 percent confidence level. The model was further extended to consider cases when projectiles were grouped together, funnels attached to the noses of the projectiles and shields placed between them.

The development of the model was centered on the assumption that the sensitivity of a projectile to detonation depended on the following properties of the striking fragment:

1. Velocity
2. Presented area
3. Angle of impact
4. Amount of charge in projectile
5. Casing thickness of the acceptor.

The model was finally used to predict the probability of detonation propagation between individual 81mm, 105mm, 155mm and 8-in projectiles, and also between groups of projectiles on pallets. Some of the results obtained using the models, especially for those cases involving individual projectiles, compared favorably with test results. In the case of grouped projectiles, parameters designed for single and groups of four projectiles were used in the model to predict the probability of detonation propagation between two similar groups of sixteen and seventy-two 105mm and 81mm projectiles, respectively. This approach was taken merely to determine the adequacy of the model. Further tests have to be carried out to determine the values of the parameters in question.

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INTRODUCTION

Background

An analytical model to predict the spacings between adjoining projectiles necessary to achieve any given level of probability that a detonation will not propagate from one to another was developed by Arthur D. Little, Inc. (ref. 1).

This model is based on theoretical and empirical information that has been compiled by previous investigators (refs. 2 to 6). A limited number of experiments were then performed by ADL to test some assumptions made and to evaluate the overall adequacy of the model.

The development of the model was centered on the assumption that the sensitivity of an acceptor projectile to detonation (50 percent of the time) depends on the following parameters:

1. Presented area of fragment
2. Velocity of fragment
3. Obliquity angle at impact
4. Casing thickness of projectile
5. Type and size of charge in projectile.

Using this model, safe separation distances between projectiles, which will result in the detonation being propagated 50 percent of the time, were calculated for the 81mm, 105mm and 8-in projectiles, each filled with Composition B. These spacings were compared with test data obtained from safe separation from tests performed, and a good correlation was obtained between the two sets of data after some necessary refinements had been made.

Objectives

The overall purpose of this study is to develop a more reliable model to predict safe separation distances between explosive items.

The objectives of this report can be summarized as follows:

1. To review the ADL model and incorporate modifications in it so as to extend its applicability to various practical situations common to AAP facilities.
2. To apply the modified model to a series of explosive propagation cases of such current interest as
 - a. Four (2 x 2) 155mm projectiles
 - b. Individual 8-inch projectiles
 - c. Twenty-four (6 x 4) 155mm projectiles
 - d. Sixteen (4 x 4) 105mm projectiles

and to compare the results with available experimental data.

3. To increase the level of reliability of the present (ADL) model and extend its applicability to include the following situations:
 - a. Multiple projectiles - The probability of explosive propagation between pallets loaded with projectiles.
 - b. Shielding between pallets.
 - c. Loading funnels - Funnel filled with Composition B attached to the nose of each projectile.
4. To pinpoint areas where additional information, theoretical and/or experimental, is required in order to further refine the model.

Format and Scope of Report

The entire report is divided into two parts which are further subdivided into three sections each. The first part of the report describes the modified (and more reliable) model, considering the pertinent topics of fragmentation and sensitivity. These include initial fragment velocity, fragment mass distribution, effect of fragment shape on velocity, sensitivity of encased charge and the effect of the angle of obliquity on the sensitivity of the charge. The probability of detonation for a given distance, a procedure for calculating this probability, and a discussion of the results obtained by such a procedure are also presented in the final section of the first part of the report.

The second part of the report, which begins under the section "GROUPED AND SHIELDED PROJECTILES", deals basically with the extension of the model (described in the first part of the report), to include such factors as the number and velocity of fragments emitted from a group of projectiles. The first few sub-sections deal with the description and the development of the model that had been modified to predict the probability of explosion propagation between grouped and/or shielded projectiles. The final section is a brief discussion of the results that can be obtained from the new model. In addition, appendix A contains sample calculations incorporating ideas developed in both parts of the study. Appendix B provides the format of the input data cards and also the program listing and, finally, appendix C presents recommended steps to follow when projectiles are grouped in a configuration other than that dealt with in this study.

DESCRIPTION OF THE MODEL

General

The evaluation of the adequacy of the ADL model was achieved through tests that were performed by James Dobbie et al (ref. 1). Such tests were not possible for this study and, as such, all modifications and extensions to the ADL model were achieved through the analysis of experimental and theoretical information collected from different sources. In the following paragraphs, the ADL model is reviewed and, where warranted, changes are made accordingly.

In the course of this study, it was necessary to develop a computer program to automate the prediction calculation at each stage of its development. The program was written to run on the IBM 1130 computer system and, since the programming of the analytical procedure is not a difficult task, the program can be modified to run on any system.

Areas of Modification

An alternate failure criterion as expressed by the Feist equation (ref. 7) was defined by Picatinny Arsenal. The penetration of the steel casing of the projectile, even without detonation, was a mode of failure that had to be considered. As a result, the sensitivity equation and factors affecting the critical velocity had to be re-examined.

The influence of certain assumptions and coefficients (inherent in various empirical relationships for fragment characteristics in the ADL model) on the predicted separation distances was examined and alternate formulations were considered. For example, the value for Gurney's constant for Composition B used in the ADL model is approximately 11 percent higher than the value cited in reference 6.

Fragment Characteristics

1. Initial Fragment Velocity

The average initial velocity of fragments from an exploding container can be estimated using the Gurney equation which assumes that the charge consists of an evenly distributed explosive in a cylindrical metal case:

$$V_0 = (2E)^{1/2}[(C/M)/(1 + C/2M)]^{1/2} \quad (1)$$

where $(2E)^{1/2} = 8,800$ fps (Gurney's constant)

C = weight of charge

M = weight of casing

V_0 = initial velocity at center polar zone.

The C/M ratio takes into account only the metal in the walls of the casing (ref. 6). Therefore, this equation is applicable to the cylindrical segment of the projectile (the sidewalls), and the nose and base area have to be excluded. Bearing this in mind, the above equation can be rewritten as:

$$V_0 = (2E)^{1/2} [2Q/(2 + Q)]^{1/2} \quad (2)$$

where $Q = C/M = [\rho_C(D - 2x)^2 / [\rho_m 4(D-x)]] \quad (3)$

D = outside diameter of casing (inches)

ρ_C and ρ_m = densities of charge and metal,
respectively

x = thickness of casing (inches).

Tests performed by Gurney with TNT-filled projectiles showed a fairly good correlation with the formula when $(2E)^{1/2} = 8,000$ ft/sec was used. It is generally agreed that Composition B has a higher density than TNT and since Gurney's constant varies almost linearly with the density of the explosive, some researchers have used $(2E)^{1/2} = 8,800$ fps for Composition B. As will be observed later, this value gives a better result than that quoted in reference 6.

2. Variations of Fragment Velocity and Mass with Polar Angle

When a projectile detonates, fragments are projected in many directions and at different velocities. Experiments have shown that for cylindrical projectiles, the greatest density of fragments is contained in a narrow beamspray generally located in the central polar zone. The fragments with greatest velocities are also found in this region which is centered at the 90-degree mark from the nose of the projectile.

Tests done with TNT-filled 155mm projectiles show this narrow region to be centered about the 95-degree mark, reinforcing the idea that the beamspray is generally slightly displaced from the 90-degree mark away from the point of initiation. Using these test results, a formulation for the initial velocity of fragments as a function of the polar zone was achieved:

$$V_i = V_0 F_V(\theta) \quad (4)$$

$$\text{where } F_V(\theta) = 0.6474 - 0.02636\theta + 0.0006095\theta^2 \\ - (3.08 \times 10^{-6})\theta^3 \quad (5)$$

$$50^\circ \leq \theta \leq 95^\circ$$

For $95^\circ < \theta \leq 185^\circ$, $(190^\circ - \theta)$ is substituted in the equation above.

The same formulation can be obtained for mass of fragments. Again, using the same test results, the weight of fragments in any polar zone centered at θ degrees from the nose of the projectile can be approximated as:

$$M(\theta) = C F_m(\theta) \quad (6)$$

$$\text{where } F_m(\theta) = 2.74326 - 0.094875\theta + 0.00097694\theta^2 \\ - (2.388 \times 10^{-6})\theta^3 \quad (7)$$

$$50^\circ \leq \theta \leq 95^\circ$$

and similarly, $95^\circ < \theta \leq 185^\circ$, use $(190^\circ - \theta)$ in equation above.

C = total weight of sidewalls of casing (oz).

To determine the average weight of fragments ejected from a fragment projectile, the equation developed by R.I. Mott can be used (ref. 8):

$$L_n[N(m)] = L_n[C' M_A] - M/M_A \quad (8)$$

$$\text{where } M = m^{1/2} \text{ (oz)}$$

$$C' = C/2M_A^3$$

M_A = is a fragment distribution parameter expressed as

$$Bx^{5/6}(D - 2x)^{1/3}[1 + x/(D - 2x)] \quad (9)$$

$N(m)$ = no. of fragments with weight $> m$

B = explosive constant (approximately 0.283 for Composition B)

m = weight of fragment (oz)

x = casing thickness (in)

D = average outside diameter of casing (in)

C = casing weight (oz).

It should be noted that Mott's equation assumes the projectile casing to be a cylinder with a uniform casing thickness. Although this is hardly the case, satisfactory results have been obtained with this equation (ref. 3).

Mott's equation can be re-written as:

$$\ln[N(m)] = \ln[C/2M_A^2] - m^{1/2}/M_A$$

$$\ln[2M_A^2 N(m)/C] = e^{-m^{1/2}/M_A}$$

For total number of fragments, $m = 0$ and therefore

$$N = C/2M_A^2$$

Average fragment weight

$$m_0 = C/N = 2M_A^2 \quad (10)$$

The ADL expression for average fragment weight is based on Heppner's formulation (ref. 4). This formulation ($m_0 = 2(K_0 D_d/V_0)^2$) gives a value for average mass of fragment (for the 155mm projectile) that is 40 percent higher than that predicted by the Mott equation which compares well with test results (ref. 9).

3. Effect of Fragment Shape on Velocity

The velocity of a fragment of known mass and presented area at a distance R feet from point of initiation can be approximated by:

$$V_S = V_0 e^{(-k'R/m^{1/3})} \quad (\text{ref. 10}) \quad (11)$$

where $k' = (A/m^{2/3})\rho_a C_D$

V_S = striking velocity of fragment at distance
R (ft)

V_0 = initial velocity of fragment (fps)

R = distance from source (ft)

A = presented area of fragment (in^2)
or fragment impact area

ρ_a = air density (oz/in^3)

C_D = drag coefficient.

The above equation can be rewritten as:

$$V_S = V_0 e^{(-0.0025Sm^{-1/3})} \quad (\text{ref. 1}) \quad (12)$$

S = distance from donor source (in)

m = mass of fragment (grain)

Sensitivity

The sensitivity equation given by ADL is based on the original work of Slade and Dewey (ref. 11) in which cylindrical fragments were fired against bare and cased charges (tetryl and Composition B). It was concluded that the velocity for 50 percent initiation was a function of contact area and not the mass of the striking fragment, and this velocity increased approximately linearly with the thickness of the cover plate of charge. Experiments carried out by Picatinny Arsenal (ref. 12) tend to disprove Slade and Dewey's theory. However, enough data was not available to reach a decisive conclusion.

To be able to design the model to predict the 50 percent velocity, ADL used the same criteria used by Slade and Dewey; that is, the 50 percent velocity which was defined as the velocity at which break-up and total detonation of charge were

equally probable. This velocity was calculated whenever possible by taking the arithmetic mean of the highest velocity for break-up and the lowest for detonation.

Since it is an objective of this study to improve the reliability of the model, it was necessary to re-analyze the Slade and Dewey data using the lowest velocities at which some deflagration occurred. By considering these velocities as critical, and also considering the linear variation of these velocities with the thicknesses of the cover plate, a formulation was achieved defining the velocity required for partial detonation (see figs. 1 and 2).

For a cylindrical fragment of diameter d striking at zero impact angle, the required velocity can be expressed as:

$$V_S = (1 + K_1 x/d) J d^{-a} \quad (13)$$

$$J = \begin{cases} (1820.74 \text{ Composition B}) \\ (1030.77 \text{ tetryl}) \end{cases}$$

$$a = \begin{cases} (0.61 \text{ Composition B}) \\ (0.42 \text{ tetryl}) \end{cases}$$

V_S = striking velocity (fps)

x = thickness of acceptor plate (in)

d = diameter of fragment (in)

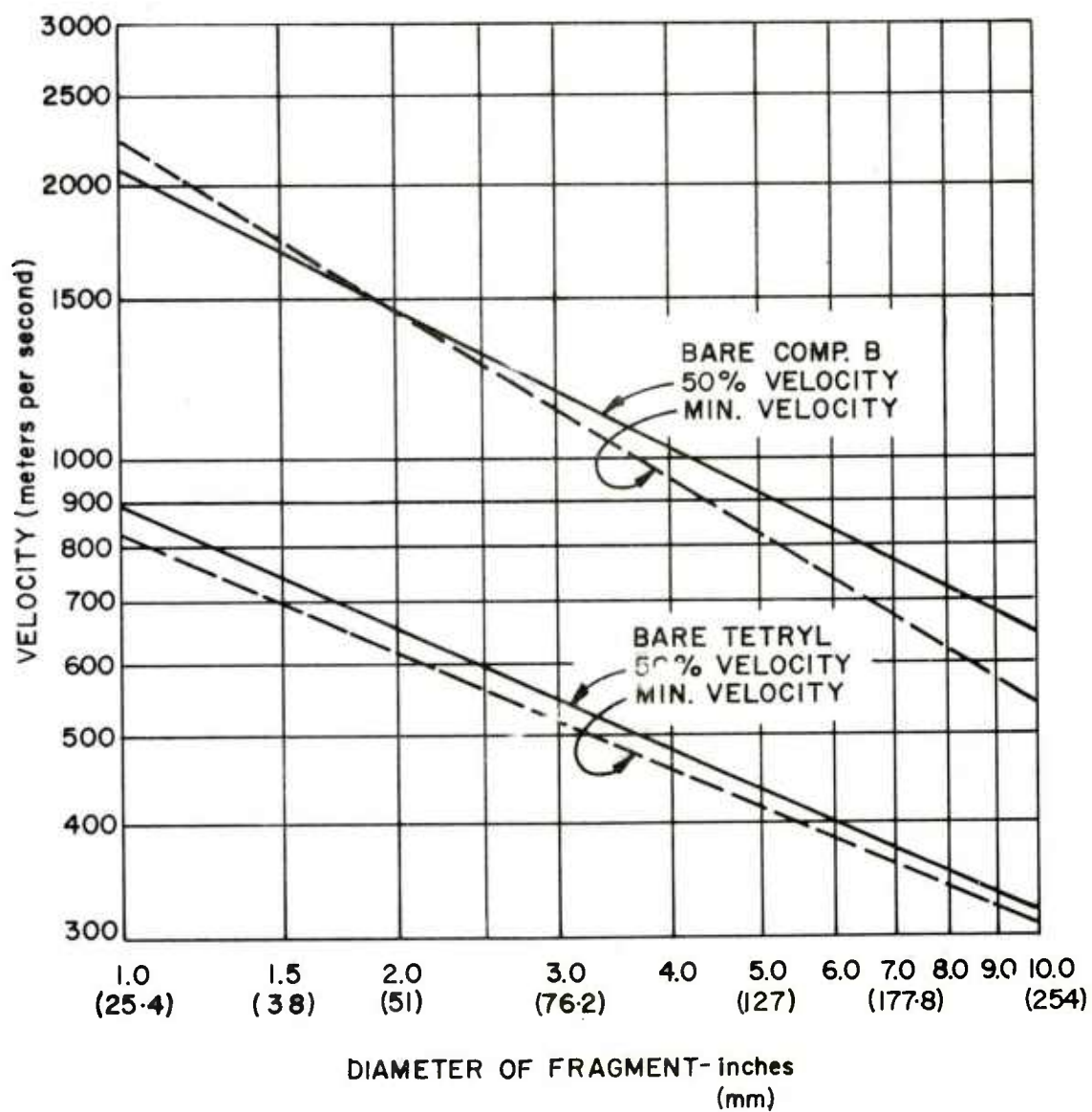
K_1 = ADL constant (0.6 - 0.8)

J and a are proportionality constants

Velocity predicted by the above formula is less than that predicted by ADL's sensitivity equation, but greater than the velocity required to just penetrate a steel cover plate of thickness x (in).

Effect of Obliquity

Analyses of data from Slade and Dewey showed that the lowest velocity required for partial detonation varied approximately the same way as the 50 percent velocity varies with the angle of impact of the fragment. Therefore, any analysis here would be identical to that presented by ADL (see fig. 3).



**FIGURE I. VARIATION OF VELOCITY
WITH FRAGMENT DIAMETER**

(from Slade & Dewey, BRL Report No. 1021)

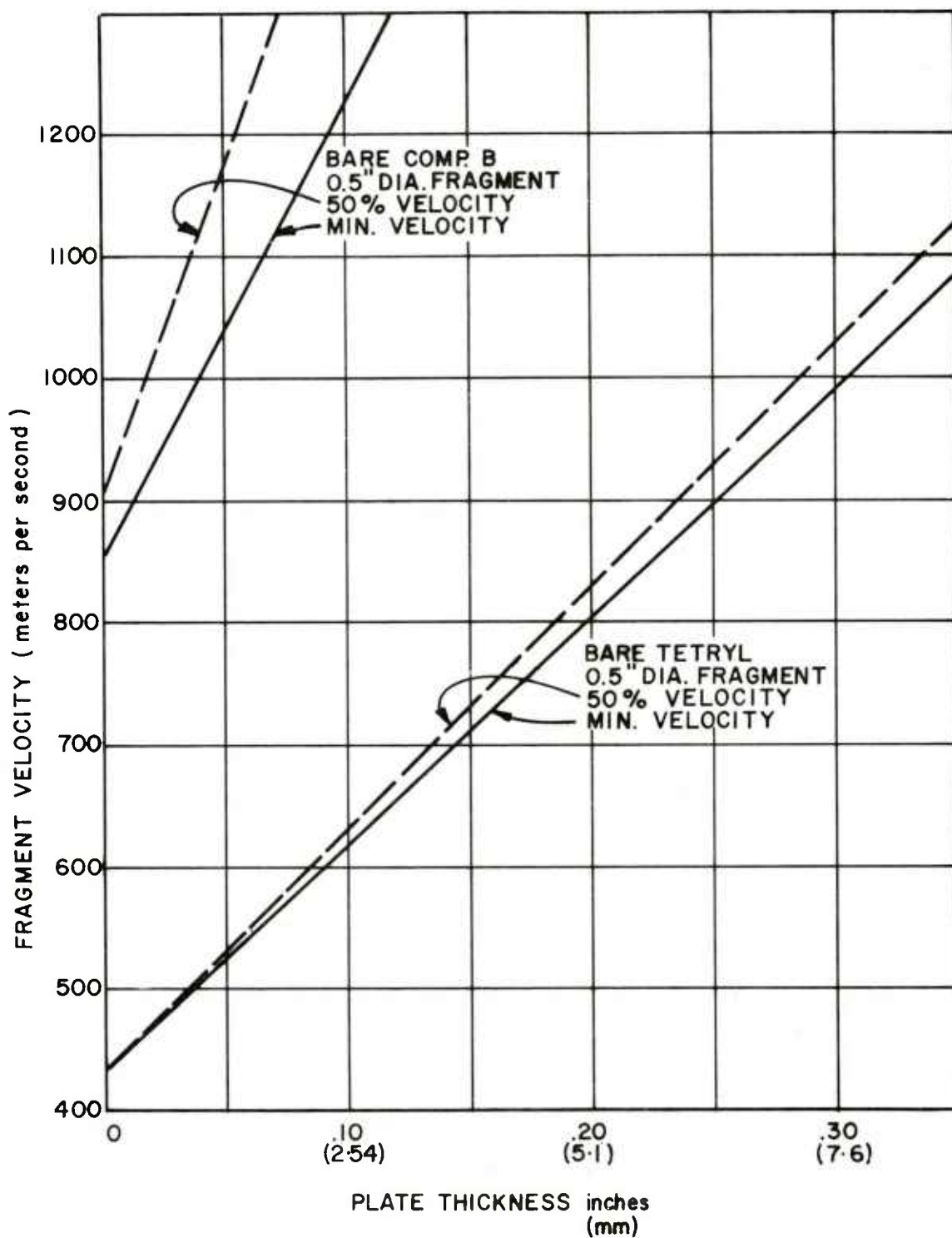
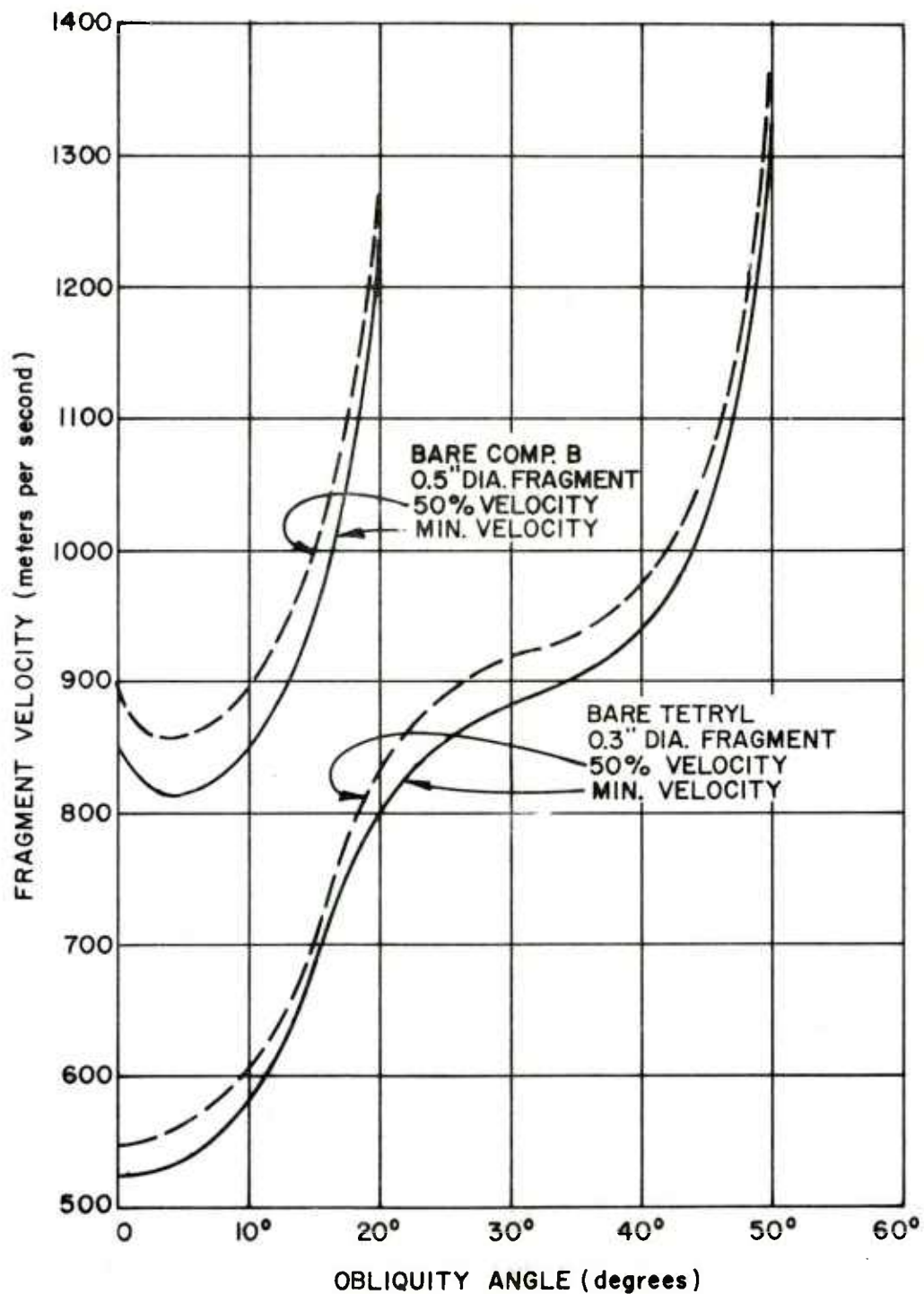


FIGURE 2. VARIATION OF BOUNDARY VELOCITY WITH PLATE THICKNESS

(from Slade & Dewey, BRL Report No. 1021)



**FIGURE 3. VARIATION OF VELOCITY
WITH IMPACT ANGLE**

(from Slade & Dewey , BRL Report No. 1021)

COMPUTATION OF PROBABILITY OF DETONATION FOR A GIVEN SPACING

Probability of Detonation as a Function of Distance

From information available in ADL's report, we can estimate the expected number of fragments in any zone. We can also calculate the expected number of effective hits (i.e., hits capable of causing detonation) at an acceptor at some distance S from explosion:

$$\bar{N}_i = \bar{N}_i f_i F_{\alpha i} F_{zi} \quad (14)$$

$$\text{where } F_{\alpha i} = (D_i - 2x_i)/2S \quad (15)$$

$$\bar{f}_i = k_3 \exp[-(m_i)^{1/2}/M_A] \quad (16)$$

$$N_i = CF_m(\emptyset)/m_0 \quad (17)$$

D_i = average outside diameter of acceptor (in)

x_i = average case thickness of acceptor (in)

m_i = critical mass in polar zone

F_{zi} = fraction of the i^{th} 10-degree zone

M_A = fragment distribution parameter (eq. 9)

$F_{\alpha i}$ = fraction of the 360-degree azimuthal angle intercepted by the acceptor

\bar{f}_i = fraction of fragments that strike acceptor that are supercritical

N_i = expected number of fragments in the i^{th} zone

\bar{N}_i = expected number of supercritical hits in the i^{th} zone

The total number of supercritical hits is

$$N = \sum_{i=1}^{\text{zone}} \bar{N}_i \quad (18)$$

and the chance of at least one supercritical hit at the acceptor is

$$P = 1 - e^{(-N)}. \quad (19)$$

The relationships discussed above supply us with a method for predicting the probability of detonation propagation for a given distance. The derivation of these equations was done by ADL. There was no need to repeat the derivations here, and since this study is an extension of that done by ADL, the interested party should consult the ADL report.

Procedure for Computing the Probability of Detonation as a Function of Spacing

All the equations presented in the earlier sections have been collected here in order to design a procedure for calculating the probability of detonation. The derivation of some of these equations can be found in the report prepared by Arthur D. Little, Inc. The probability of detonation of acceptor shall be calculated from the following steps:

Step 1:

Measure from a scaled drawing of the projectile:

D = the average outside diameter at the middle section

x = the average casing thickness.

Step 2:

Calculate the initial velocity of fragments using equation (2):

$$V_0 = (2E)^{1/2} [2Q/(2 + Q)]^{1/2}.$$

For this velocity, the charge-to-metal ratio has to be calculated. This is achieved by using equation (3). Gurney's constant should be taken as 8,880 fps for Composition B.

Step 3:

On a scaled drawing as shown in figure A.1, with donor and acceptor projectiles spaced S (in) center to center and their bases on the same level, lay off the dividing rays for polar zones of 10 degrees centered at integral multiples of

10 degrees. Determine the zones in which fragments can hit the acceptor, ignoring the base plate and fuze section. Estimate the fraction F_{Zi} of the zone over which the vulnerable part of the acceptor extends. $F_{Zi} = 1.0$ for zones completely spanned. If S is large enough that only the central zone is involved, then

$$F_Z = 18H/\pi S$$

where H = height of vulnerable portion of projectile. Also, estimate the average outside diameter (in) and thickness of casing (in) in each zone.

Step 4:

For each zone, compute the critical mass m_i (grain) by iteration from the following equations:

$$F_{Di} = e(-0.0025Sm_i^{-1/3}) \quad (20)$$

$$V_i = V_0 F_{Vi} F_{Di} \quad (21)$$

$$d = (4F_A/\pi)^{1/2} (m_i/k)^{1/3*} \quad (22)$$

$$V_i = (1 + K_1 X/d) J d^{-a} \quad (13)$$

Starting with $m_i = m_0$, calculate F_{Di} and V_i using equation (5) to calculate F_{Vi} . For this same value of m_i , calculate d from equation (22) above, and finally calculate V_i using equation (13). Repeat this until the V_i 's given by equations (21) and (13) do not differ significantly. F_A , the fraction of the contact area of the fragment that is effective, is taken as 0.50.

Step 5:

For each zone, compute the total number N_i of fragments, the azimuthal factor F_i , and the fraction f_i of the striking fragments that have mass exceeding the critical mass m_i using the following operations:

*Equation (22) was derived by ADL for the sensitivity equation to take into account the mass of the striking fragment. The iterative process in this section can be time-consuming unless one of the advanced numerical techniques, for example, the secant method, is used.

$$N_i = CF_m(\emptyset)/m_o \quad (6)$$

$$F_{\alpha i} = (D_i - 2X_i)/2\pi S \quad (15)$$

$$\bar{f}_i = F_I e^{-(2m_i/m_o)^{1/2}}$$

$F_m(\emptyset)$ is calculated from equation (7). F_I , another factor derived by ADL, considers the effect of non-normal impacts and it is estimated to be 0.2 for Composition B. C is the total weight of the casing sidewalls (grain).

Step 6:

The probability of detonation can now be calculated using the following:

$$N = \sum_{i=1}^z N_i F_i F_{Zi} f_i \quad (18)$$

$$P = 1 - e^{(-N)} \quad (19)$$

z = number of zones involved.

Discussion of Results

To improve the reliability of the ADL model, calculations were done for the 81mm (M374A1 Comp B) projectiles and results compared with those presented in reference 13. The calculations were performed on the computer and the input and output data are presented in appendix A.

Certain notable changes made in the ADL model were:

1. The value of the shape factor k (or ballistic density): This value expresses the relationship between fragment mass and projected areas. A k factor of 660 grains per cubic inch was found to yield a more accurate value of the separation distance than that quoted in the ADL report (640 grams/cu in). Reference 9 makes use of the same value.
2. Area Factor F_A : Calculations showed that a value of 0.5 provided better results than 0.75 as presented in the ADL report. Tests showed the average fragments had at least one pointed side, thus reducing the ratio of the effective area to the presented area.

3. Protection Coefficient K_1 : A closer examination of the results presented in reference 3 indicated $K_1 = 0.8$ to be a better approximation.

With the above changes made, the necessary parameters and dimensions of the projectile were inputted into the program in the format shown in appendix A. For a distance of 21.08 inches between individual 81mm projectiles, the probability of detonation propagating from one to the other was found to be 6.4 percent. Tests performed by Picatinny Arsenal (ref. 13) gave a probability of 5.1 at 95 percent confidence level for the same separation distance. The insignificant difference between the values predicted by the updated model and experiments is a consequence of the conservative assumptions made in the model.

Calculations were also performed for the 155mm projectiles with separation distances of 1.68 m (66.1 in) and 2.29 m (90.1 in). For both distances, the model predicted a probability of detonation of 12.7 and 8.7 percent, respectively. These predictions were compared with the test results documented in reference 14. For a separation distance of 2.29 m (90.1 in), one out of 12 projectiles resulted in a high order detonation which is equivalent to a probability of 8.3 percent. However, for a confidence level of 95 percent and 11 observations with no reactions, the probability of explosion propagation will fall between zero and 28.5 percent.

For a separation distance of 1.68 m (66.1 in) and a confidence level of 95 percent, the true value of the probability of explosion propagation was between the zero to 45.9 percent interval. This relatively wide interval is based on six observations, as the number of observations increases, the confidence level increases (the interval decreases).

Calculations were again performed for the same projectiles and separation distance, but this time the new alternate failure criterion (perforation of casing even without high order detonation) was considered. The model predicted a probability of detonation of 36 percent for a separation distance of 21.08 inches between individual 81mm projectiles. The accuracy of this prediction could not be determined due to the unavailability of test data in which perforation of casing was considered a failure criterion.

GROUPED AND SHIELDED PROJECTILES

General

The reliability of the model developed by ADL was improved in part 1 of this report. The model designed to predict the probability of detonation propagation between adjacent explosive items was refined to incorporate the alternate failure criterion proposed by ARRADCOM.

As part of the overall objective of this study, the model is extended to predict "safe distances" for a much broader range of practical configurations such as:

1. Four (2 x 2) 155mm projectiles on pallets
2. Twenty-four (6 x 4) 155mm projectiles on pallets
3. Sixteen (4 x 4) 155mm projectiles on pallets.

Certain elements that influence the safe separation distance are examined. These include situations when plate or bar shields are placed between stacked projectiles and when funnels are attached to the noses of the projectiles on the pallets.

The depth and accuracy of this portion of the study is adversely limited by the unavailability of experimental data. Most of the equations and discussions presented in this section are based entirely on the analysis of data available in Technical Report No. 3664, "Fragment Hazard Program", by Richard T. Ramsey, et al (ref. 9).

Characteristics of Fragments Emitted from a Group of Projectiles

In the case of an individual projectile, it was assumed that the source of the emitted fragments was rotationally symmetric about the longitudinal axis and thus the properties of the fragments were functions of the polar angle only. Test results show that this assumption is not valid for grouped or stacked projectiles. Properties of fragments emitted from such a group are functions of the polar and azimuthal angles.

However, when the projectiles are grouped in a "square matrix" arrangement, it can be conservatively assumed that rotational symmetry for such a group exists. Tests documented in reference 9 show the above assumption to be fairly accurate.

Due to the limited availability of data on group projectiles, consideration would be given to the square matrix arrangement. Extension of the model to include any stack configuration should not be a difficult task.

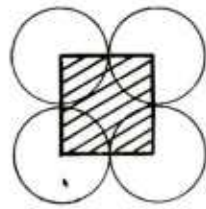


Figure 4

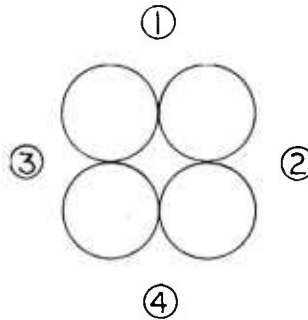


Figure 5

Other assumptions that have to be made for group projectiles in a square matrix arrangement include:

1. The metal in the shaded region in figure 4 does not enter the fragment mass distribution.
2. Targets 1, 2, 3 and 4, situated at the same distance from the donor, have equal probabilities of being hit by fragments emitted from the group (this follows from the assumption that the source is rotationally symmetric about its longitudinal axis).

It should be emphasized that the above assumptions would lead to results that are very conservative and they are also only valid for the arrangement shown in figure 5. When a number of projectiles other than four (2 x 2) are grouped together in a configuration other than that described above, the steps described in appendix C have to be followed. Again, it should be emphasized that the accuracy of these steps could not be determined due to insufficient experimental data.

Initial Fragment Velocity

The velocities of fragments emitted from a group of four (2 x 2) projectiles were found to be twice those from an individual projectile between the 60- and 120-degree polar angles. Outside this zone, the fragment velocities were approximately 1-1/2 times those for a single projectile (ref. 9).

The beamspray was also found to be centered around the 103-degree mark unlike the 95-degree mark in the case of a single projectile. This 8-degree shift affects the velocity parameter $F_v(\theta)$. To determine $F_v(\theta)$ for a group of four projectiles, $(\theta - 8)$ should be used in equation (5) for $13 \leq \theta \leq 103$ and for polar angles between 103° and 198° $(198 - \theta)$ should be used.

Fragment Mass Distribution

From assumption 2, the distribution parameter $F_m(\theta)$ defined in equation (7) can also be used. However, due to the 8-degree shift in the location of the beamspray, $(\theta - 8)$ should be substituted for θ in equation (7) for $13 \leq \theta \leq 103$ and $(198 - \theta)$ is used for angles outside this limit. The mass of fragments emitted from a stack of projectiles in a polar zone centered at angle θ can be expressed as:

$$M(\theta) = C_A F_m(\theta) \quad (6)$$

where C_A is the fraction of the total weight of metal involved in the mass distribution.

Figure 6 below shows how this value can be estimated. Test results show this method to provide estimates that are within the tolerance limit of this study.

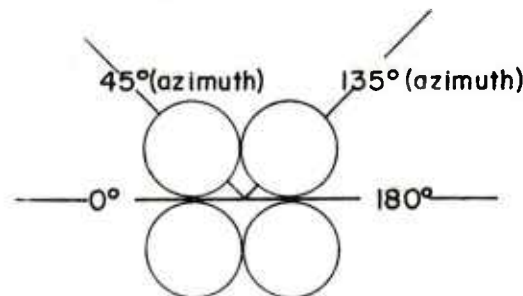


Figure 6.

Tests performed with 155mm projectiles in reference 9 showed also that the total weight of fragments from an individual projectile, collected in an area bounded by 45- to 135-degree polar zone was 61,378 grains. The average weight of metal collected in a similar area for a group of 4 projectiles was 175,747 grains (giving a ratio of approximately 3). From figure 6, the model shows 3/4 sectors of projectile metal available in a 90° azimuthal sector. This gives a ratio of 3 (3/4 projectile from a group of 4 and 1/4 from a single projectile).

The slopes of the curves in figure 7 show that the average weight of the fragments emitted from a single and group projectiles was the same. This is the expected result as predicted by Mott's equation presented in the first part of this report (eq. 10).

Effect of Shields

1. Plate Shield

Perforation data for steel impacting on several metallic materials including steel and aluminum was collected and analyzed by Ballistic Research Laboratories as part of project THOR (ref. 2). These test results showed that the residual velocity of a fragment after perforation of a medium could be expressed as:

$$V_r = V_s - 10^c (tA)^{\alpha} m_s^{\beta} (\sec \theta)^{\gamma} V_s^{\lambda} \quad (23)$$

where V_r = fragment residual velocity (fps)

V_s = fragment striking velocity (fps)

t = thickness of target (in)

A = average impact area (in²)

m_s = initial weight of fragment (grain)

θ = obliquity angle

c , α , β , γ and λ are constants and these values are listed below in table 1 for mild homogeneous steel and Aluminum Alloy 2024T-3.

Table 1

Target Material	c	α	β	γ	λ
Mild homogeneous steel	6.399	0.889	-0.945	1.262	0.019
Hard homogeneous steel	6.475	0.889	-0.945	1.262	0.019
Aluminum Alloy 2024T-3	7.047	1.029	-0.072	1.251	-0.139
Cast iron	4.840	1.042	-1.051	1.028	0.523

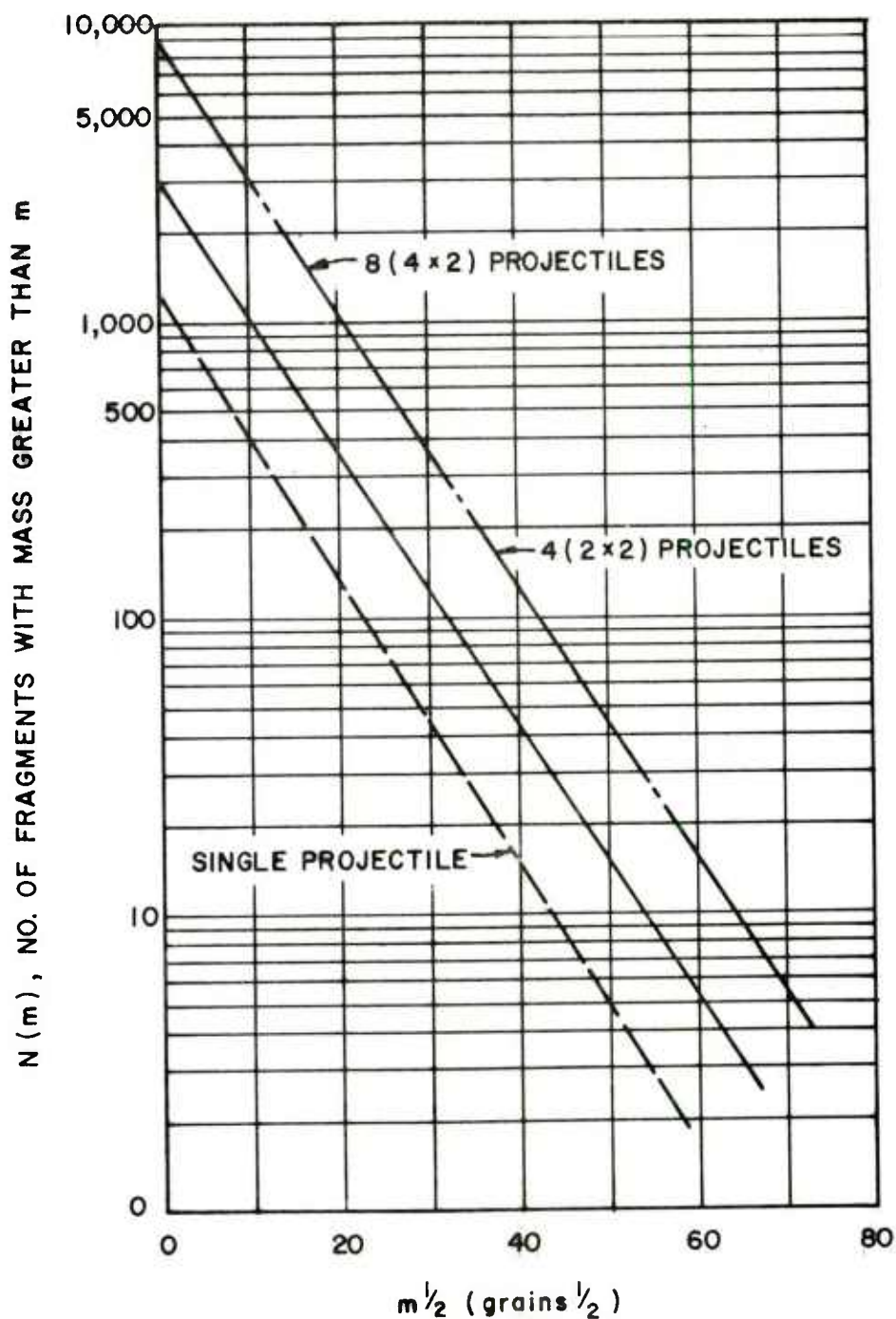


FIGURE 7. MOTT PLOTS FOR ONE (1),
FOUR (2x2) & EIGHT (4x2)
GROUPS OF PROJECTILES

(from R.T. Ramsey, Fragment Hazard Investigation Program)

By setting the residual velocity $V_r = 0$ in equation (23), a good approximation of the protection velocity can be obtained.

$$V_0 = 10^{c_1} (eA)^{\alpha_1} m_s^{\beta_1} (\sec \theta)^{\gamma_1} \quad (24)$$

where V_0 = protection velocity (fps)

e , A , m_s and θ have been defined previously.

c_1 , α_1 , β_1 and γ_1 are constants whose values are listed in Table 2.

The protection velocity V_0 is defined to be the highest striking velocity below the ballistic limit for which probability of perforating a given target is zero.

Table 2

Target Material	c_1	α_1	β_1	γ_1
Aluminum Alloy 2024T-3	6.185	0.903	-0.941	1.098
Mild homogeneous steel	6.523	0.906	-0.963	1.286
Hard homogeneous steel	6.601	0.906	-0.963	1.286
Cast iron	10.153	2.186	-2.204	2.156

After perforation, the mass of the fragment varies and again an estimate of the residual mass of the fragment can be obtained by:

$$m_r = m_s - 10^c (tA)^{\alpha} m_s^{\beta} (\sec \theta)^{\gamma} V_s^{\lambda} \quad (25)$$

Table 3 below lists the value of the constants in equation (25).

Table 3

Target Material	c	α	β	γ	λ
Mild homogeneous steel	-2.507	0.138	0.835	0.143	0.661
Hard homogeneous steel	-2.264	0.346	0.629	0.327	0.880
Aluminum Alloy 2024T-3	-6.663	0.227	0.694	-0.361	1.901
Cast iron	-9.703	0.162	0.673	2.091	2.710

The critical mass (weight of fragment to cause detonation) is calculated as a function of the residual velocity and mass. A decrease in the velocity and weight of fragment after perforation would reduce the probability of such a fragment being critical.

2. Bar Shields

Available test results with bar (or pipe) shields are not sufficient enough to be able to establish empirical relationships. However, tests performed by C. Anderson and R. Rindner of Picatinny Arsenal (ref. 14) with steel and aluminum rods placed between single and multiple 155mm projectiles (M107 Comp B) provided the following observations:

- a. The fragments from the donor projectile which are "head-on" to the critical region (a portion of the area of the projectile containing the charge) of the acceptor are deflected by the bar shield, while those fragments which miss the shield would only have a grazing impact on the projectile. However, in the case of multiple projectiles, these grazing fragments might strike normal to other projectiles in the group.
- b. Aluminum, besides being lighter and less expensive, absorbs more energy per unit weight during deformation (plastic) and behaved more uniformly than steel.

The existence of shields (bar or plate) between donor and acceptor projectiles reduces the probability of an acceptor projectile being hit by a fragment. A very

Table 4. Parameter values

Shape Factor (Ballistic Density) K (grain/in³) = 660.0

Sensitivity Parameter B = 2,140.0

Area Factor FA = 0.5

Constant J (sensitivity) = 1,820.74

Constant A (sensitivity) = 0.61

Constant B (Mott's equation) = 0.283

Average Mass Coefficient $K_0 = 4,500.0$

Protection Coefficient $K_1 = 0.8$

Impact Angle Factor $FI = 0.2$

Gurney's Constant VC (ft/sec) = 8,800.0 for Composition B
= 8,000.0 for TNT

Charge Density (lb/in³) = 0.058 for Composition B
= 0.056 for TNT

Table 5. Various explosive constants used in calculations

Explosive type	Gurney's Constant (fps)	Explosive Constant B (eq. 9)	Constant J (eq. 13)	Constant A (eq. 3)
TNT	8,000.00	0.300	-	-
Composition B	8,800.00	0.283	1,820.74	0.61
Tetryl	7,460.00	0.240	1,030.77	0.42

conservative estimate of such a probability can be obtained from the model developed in this study.

Effect of Funnels

The extra weight of funnels attached to the noses of projectiles enter the fragment weight distribution. The assumption inherent in Gurney's equation, namely, the projectile casing is cylindrical, can no longer be considered valid here. However, if the following assumptions are made, the effects of funnels can be dealt with but the validity of these assumptions cannot be justified due to insufficient experimental data.

1. The extra weights of the casing of the funnel and enclosed charge are taken into account when the C/M ratio (eq. 3) is calculated, and initial velocity is a function of this ratio and not of the outside diameter and thickness of casing.
2. Perforation of any funnel in the group will cause detonation of the entire group of projectiles.

DEVELOPMENT OF MODEL TO PREDICT PROBABILITY OF DETONATION FOR STACKED PROJECTILES

Probability of Detonation as a Function of Distance and Shielding

All of the extensions to the old model discussed in the previous section are grouped here to facilitate the development of the new model. The probability of detonation can be computed using the following equations:

1. Fragment initial velocity:

$$V_0 = (2E)^{1/2}[2\phi(2 + Q)]^{1/2}. \quad (2)$$

For a group of four (2 x 2) 155mm projectiles, initial velocity of fragments in a polar zone centered at ϕ is:

$$V(\phi)_{IN} = n V_0 F_V(\phi) \quad (4)$$

$$\text{where } n = \begin{cases} 2.0 & 60 \leq \phi \leq 120 \\ 1.5 & \text{otherwise} \end{cases}$$

$$\begin{aligned} \text{where } F_V(\phi) = & 0.6474 - 0.02636(\phi - 8) \\ & + 0.0006095(\phi - 8)^2 \\ & - (3.08 \times 10^{-6})(\phi - 8)^3 \end{aligned} \quad (5)$$

for $130 \leq \phi \leq 1030$.

For $1030 \leq \phi \leq 1980$, use $(198 - \phi)$ in the equation above.

2. Number of fragments:

$$\ln[N(m)] = \ln[C^*M_A] - M/M_A \quad (8)$$

$$\text{where } M = m^{1/2} \text{ (oz)}$$

$$C^* = C_A/2M_A^3$$

$$M_A = Bx^{5/6}(D - 2x)^{1/3}[1 + x/(D - 2x)] \quad (9)$$

The notations used above have been defined previously. The new constant C_A was also defined earlier.

3. Average mass of fragment:

Total number of fragments involved in fragment mass distribution:

$$N = C_A / 2M_A^2$$

$$\text{Average fragment weight: } m_0 = C_A / N = 2M_A^2$$

4. Striking velocity at a given distance from donor:

$$V_S = V_0 e^{(-K'R/m^{1/3})} \quad (11)$$

$$= V_0 e^{(-0.0025Sm^{-1/3})} \quad (12)$$

where S = distance (in)

m = mass of fragment.

When a shield is present between donor and acceptor projectiles, striking velocities at surface of shield and at acceptor should be calculated.

For a plate (bar) shield, striking velocity is:

$$V_{sp} = V_{IN} e^{(-0.0025S_1 m_s^{1/3})} \quad (12)$$

where V_{sp} = striking velocity of fragment at surface of plate shield (fps)

V_{IN} = initial velocity of fragment at donor source (fps)

S_1 = distance between donor and surface of shield next to donor (in)

m_s = initial fragment mass (grain)

Assuming the shield is perforated by the fragment, striking velocity of fragment at acceptor surface is:

$$V_{Sr} = V_{re}^{(-0.0025S_2 m_r^{-1/3})} \quad (12)$$

where V_{Sr} = striking velocity of fragment at acceptor (fps)

V_r = residual velocity of fragment at shield (fps)

S_2 = distance between shield and acceptor projectiles (in)

m_r = residual weight of fragment (oz)

It should be noted that S_1 is the maximum distance (in) between the donor pile and the shield that would result in the most effective use of the shield. Figure 8 shows how this distance can be calculated. A basic assumption here is that any fragment that does not perforate the shield is either blocked by it or deflected away from the acceptor projectile.

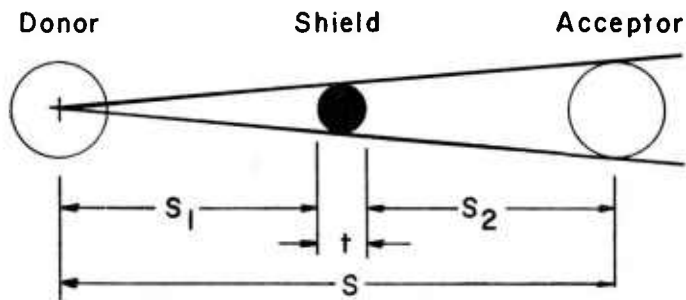


Figure 8.

5. Minimum striking velocity of a fragment of mass (m) to cause detonation:

$$V_S = (1 + K_1 x/d) J d^{-a} \quad (13)$$

$$d = (4F_A/\pi)^{1/2} (m_i/k)^{1/3} \quad (22)$$

where F_A = constant of proportionality between impact and effect areas of the fragment.

The striking velocity at the surface of the acceptor projectiles V_{S1} is calculated as a function of the residual velocity after perforation of shield, taking into account the drag effects.

After perforation of the shield, the mass of the fragment changes and so does its diameter. Equation (19) should be changed to:

$$d = (4F_A\pi)^{1/2}(m_{ir}/K)^{1/3} \quad (22)$$

where m_{ir} = residual mass in the i^{th} zone (grain).

The equations presented here would now be used to determine the probability of detonation for grouped projectiles.

Procedure for Calculating Probability of Detonation Propagation Between Stacked Projectiles

The probability of detonation propagation between stacked projectiles (4 in a group) can be determined from the following steps:

Step 1.

From a scaled drawing of a single projectile (as shown in figure A.1), determine the following:

D = outside diameter of projectile (in)

x = average casing thickness (in) should be measured around the center of the projectile.

If funnels are involved in the stack, then determine:

M = total weight of casing (oz). This includes weight of the funnel casing and the sidewalls of the projectile.

C = the total charge weight (oz) both in projectile and funnel.

Step 2.

Calculate initial velocity of fragments from a single projectile (with or without funnel) from the following equation:

$$V_0 = (2E)^{1/2}[2Q/(2 + Q)]^{1/2} \quad (2)$$

$$\text{where } Q = \rho_c(D - 2x)^2 / [\rho_m^4(D - x)]$$

for a cylindrical projectile without a funnel

or where $Q = C/M$

for a projectile with a funnel.

Step 3. (If shields have to be used.)

On a scaled drawing with donor and acceptor stacks in a horizontal position, space the distance S , and determine the maximum distance between the shield and donor stack. Figure 9 below shows how this is done.

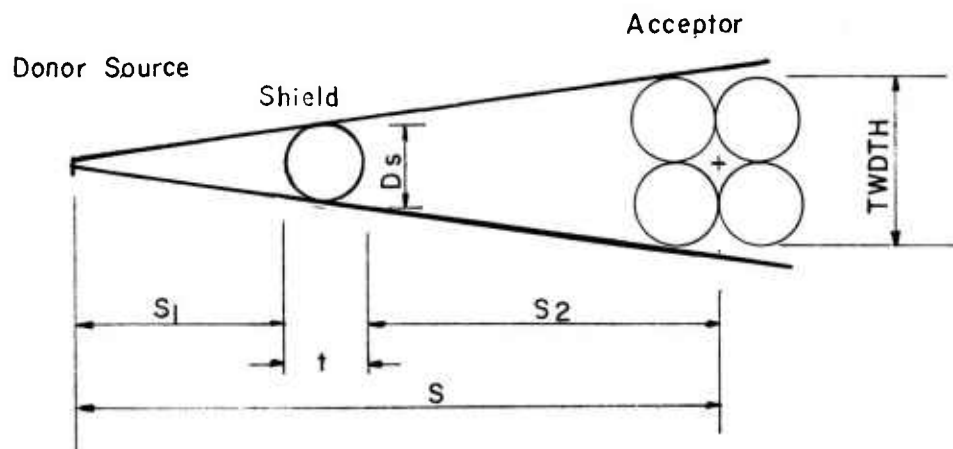


Figure 9

D_s = diameter of shield (bar) or width of shield (plate)

t = thickness of shield

S_1 = distance of shield from donor source (as shown)

S_2 = distance of acceptor group from shield (as shown)

$$(S_1 + t + S_2) / (S_1 + t/2) = TWDTH / D_s$$

$$S_1(TWDTH + D_s) = D_s(S_2 + t) - t/2(TWDTH) \quad (25)$$

Step 4.

On a scaled drawing (as shown in figure A.1) with donor and acceptor stacks spaced the distance S and their bases on the same horizontal plane, lay off the dividing rays for polar zones of 10° centered at integral multiples of 10° . Determine zones in which fragments can hit the acceptor projectiles, ignoring the base plate and fuze section if no funnels are involved. As stated earlier, estimate the fraction F_{Zi} of the zone over which the vulnerable part of the acceptor extends. $F_{Zi} = 1.0$ for zones completely spanned. If S is large enough that only the central zone is involved, then

$$F_Z = 18H/\pi S$$

where H = height of the vulnerable portion of the projectile.

If funnels are involved, then H is the combined height of the projectile and funnel, ignoring only the base plate.

Also estimate the average outside diameter of projectile (in), casing thickness (in), and the angle of impact at the surface of the shield for each zone.

Step 5.

Assuming that there is no decrease in the weight of a fragment after perforation, the iterative process is greatly simplified. For each zone, compute the critical mass m_{ri} (grain) by iteration from the following equations:

$$F_{Di} = e^{(-0.0025S_2m_i^{-1/3})} \quad (20)$$

$$C_{Di} = e^{(-0.0025S_1m_i^{-1/3})} \quad (26)$$

$$V_{INi} = V_o F_{Vi} \quad (27)$$

$$V_{spi} = V_{INi} C_{Di} \quad (28)$$

$$A = (m_i/k)^{2/3} \quad (29)$$

$$V_{pi} = 10^{C_1} (tA)^{\alpha_1} m_i^{\beta_1} (\sec \theta)^{\gamma_1} \quad (30)$$

$$V_{ri} = V_{spi} - 10^C (tA)^{\alpha} m_i^{\beta} (\sec \theta)^{\gamma} V_{spi}^{\lambda} \quad (31)$$

$$V_{sri} = V_{ri} F_{Di} \quad (32)$$

$$d = (4F_A/\pi)^{1/2}(m_i/k)^{1/3} \quad (22)$$

$$V_{sri} = (1 + K_1 x/d) J d^{-a} \quad (13)$$

Starting with $m_i = m_0$, if $V_{pi} > V_{spi}$ for any value of m_i , then the fragment does not perforate the shield. By setting m_i to be equal to a large value (5,000 grains), the probability of such a fragment with zero residual velocity causing detonation is automatically set to zero.

Step 6.

For each zone also, compute the total number of fragments N_i , the azimuthal factor $F_{\alpha i}$ and fraction \bar{f}_i of the striking fragments that have mass exceeding the critical mass m_i using these equations:

$$N_i = C_A F_m(\emptyset) m_0 \quad (17)$$

$$F_{\alpha i} = 2(D - x)/2 (S_1 + e + S_2) \quad (33)$$

$$\bar{f}_i = F_{Ie} - (2m_{ri}/m_0)^{1/2} \quad (16)$$

Step 7.

The probability of detonation is calculated as follows:

$$N = \sum_{i=1}^Z N_i F_{\alpha i} F_{Zi} f_i \quad (14)$$

$$P = 1 - e^{-N} \quad (19)$$

The notations above have been defined previously in an earlier section of the report.

DISCUSSION OF RESULTS

Although the second part of the report dealt mainly with stacked projectiles, calculations were done to predict the probability of detonation propagating between adjoining individual 155mm (M107 Comp B) projectiles with and without plate shields between the projectiles.

With no shield present, the model predicted a probability of detonation of 49 percent for a distance of 0.61 m (24.1 in), but the confidence level could not be determined. However, when a 0.5-inch thick steel plate was placed between the two projectiles, the probability of detonation was zero for the same distance. Tests were done with the same projectiles, same thickness of shield and same spacing between projectiles, and out of 48 trials, no detonation of the acceptor projectile was observed (ref. 14). The number of tests is enough to give a high confidence level. Sample calculations are presented in appendix A.

Calculations were also done for groups of 81mm and 105mm projectiles to determine the adequacy of the model. No favorable correlations were expected since parameters designed for single and groups of four (2 x 2) projectiles were used in the model to predict the probability of explosion propagation between groups of 16 (4 x 4) 105mm and 72 (6 x 12) 81mm projectiles.

For a separation distance of 109.7 m (360.0 in) between two groups of 16 (4 x 4) 105mm (M1) projectiles, the model predicted a probability of detonation of 20.6 percent compared to 10 percent at a 95 percent confidence level provided by test results. Similarly, the model predicted a probability of detonation of 2.4 percent for a separation distance of 0.914 m (36.0 inches) between two groups of 72 (6 x 12) 81mm (M374A1) projectiles. Test results gave a probability of 6.8 percent at a 95 percent confidence level (refs. 13 and 15).

Finally, the model was used to predict the probability of detonation for individual 8-in (M106) HE projectiles spaced at a distance of 0.305 m (12 inches) with a 3-inch diameter aluminum bar placed between the donor and acceptor projectiles. The model came up with a probability of zero. Test results show that out of 50 observations, no propagation was observed thus providing an upper limit of 7.1 percent for a confidence level of 95 percent (ref. 16).

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The model and procedures described in this report provide a rational basis for determining the probability of detonation propagation between adjoining explosive items. From the analysis of available data and calculations provided in this report, the following conclusions have been reached:

1. When used in a generalized way, the model can be a valuable tool in the design and layout of facilities for the manufacture and storage of explosive items.
2. To compute the required separation distance S between projectiles for a given probability, the model can be used to determine the probability of detonation for trial values of S until a correct value is found. This was determined to be the most accurate means.
3. Certain approximations and assumptions made affect the accuracy of the model, especially when stacked projectiles are involved. The accuracy would be enhanced by appropriate experiments such as those recommended below.

Recommendations

The following recommendations are made:

1. Perform further analyses of this modified model in the areas that cover shields, funnels and stacked projectiles.
2. Design a test plan covering areas which should be further investigated experimentally such as arena, fragmentation and sensitivity tests.
3. Perform arena tests for projectiles stacked in configurations of interest, with the view of collecting information on velocity, polar and azimuthal distribution of the fragments.
4. Perform fragmentation tests to determine the number of fragments emitted from different configurations of stacked projectiles (and the distribution of these fragments).

5. Perform sensitivity tests (similar to the ones begun in ref. 12) to accurately determine the relationship between boundary velocity and each of the following:
 - a. Fragment mass
 - b. Presented (or impact) area of fragment
 - c. Thickness of acceptor plate.

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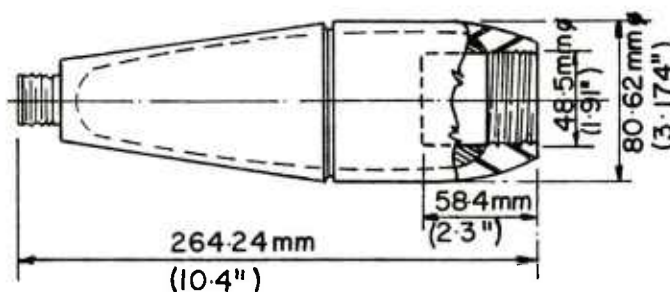
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APPENDIX A EXAMPLE PROBLEMS

Sample Calculations

1. 81mm (M374A1) Projectile with No Shields



Average Outside Diameter	$D_i = 3.04$ inches
Average Casing Thickness	$X_i = 0.29$ inch
Height of Charge in Projectile	$H = 7.2$ inches
Density of Enclosed Charge (Comp B)	$\rho_c = 0.058$ lb/in ³
Density of Metal (Steel)	$\rho_m = 0.283$ lb/in ³
Mass of metal (Sidewalls)	$M = 5.0$ lb = 35,000.0 grains

Input Table (A.1). 81mm Projectiles

Zone	Polar angle (deg)	FZ	FV	FM	Casing thickness (in)	Outside diameter (in)
1	80	0.57	0.862	0.183	0.29	1.91
2	90	1.00	0.967	0.377	0.29	3.04
3	100	0.43	0.969	0.377	0.29	3.08

Note: The casing thickness and outside diameter for each zone are measured at the point where the centerline of that particular polar zone intersects the centerline of the projectile.

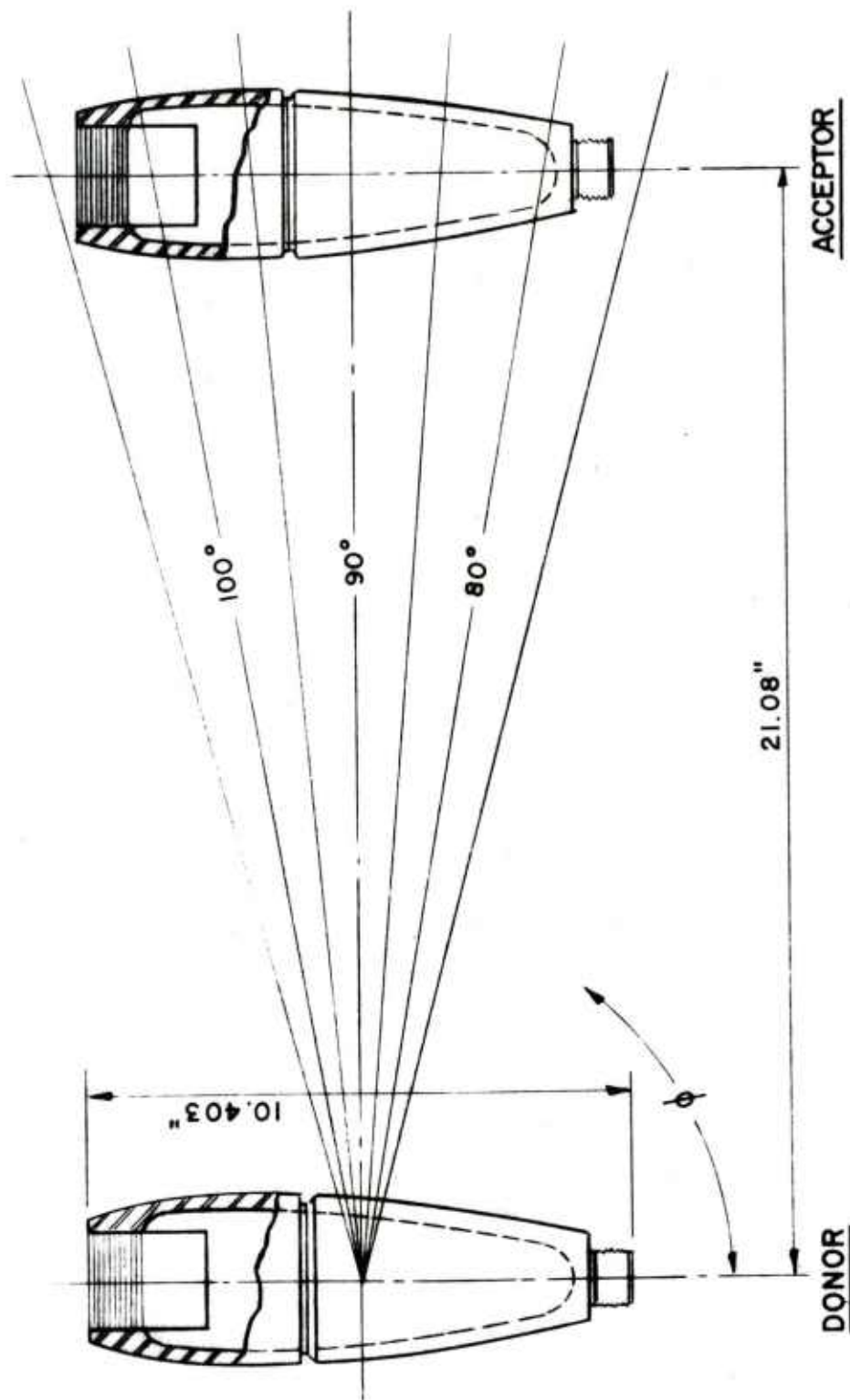


FIGURE A.1 81 mm (M374A1) projectiles

Input Format - Example 1

Card Type 1

NCASE = 0

NPROJ = 1

Card Type 2

Title: 81-mm (M374A1) Projectiles (Comp B)

Card Type 3

Type of Shield: None

Card Type 4 (Needs decimal points)

VC = 8800.0

DENC = 0.058

DENM = 0.283

SK = 660.0

XM = 35000.0

H = 7.2

XD = 0.29

DD = 3.0

Card Type 5

C0 = 4500.0

SB = 2140.0

C1 = 0.8

FA = 0.5

FI = 0.2

PLATE = 0.

Card Type 6 (A blank card can be substituted)

ALPHA = 0

BETTA = 0

GAMMA = 0

CONST = 0

XLAMD = 0

Card Type 7 (A blank card can be substituted)

ALPH1 = 0

BETA1 = 0

GAMA1 = 0

CONT1 = 0

Card Type 8

SA = 0.61

CB = 0.283

XJ = 1820.74

Card Type 9

S = 21.08

NZONE = 3

NMIS = 1

TWDTH = blank. This value can be left out since it only
applies to stacked projectiles.

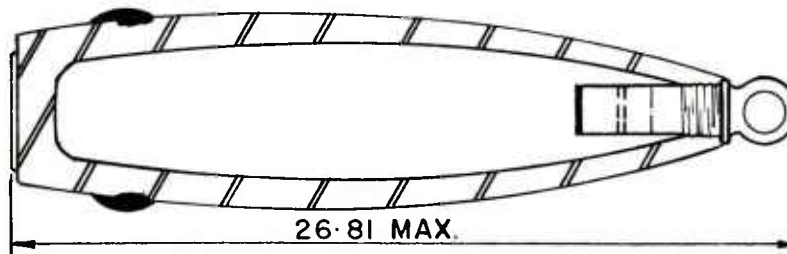
Card Type 10 (Values are taken from Input Table A.1). One card required for each zone.

<u>1st Zone</u>	<u>2nd Zone</u>	<u>3rd Zone</u>
FZ = 0.57	FZ = 1.0	FZ = 0.43
FV = 0.862	FV = 0.967	FV = 0.967
FM = 0.183	FM = 0.377	FM = 0.377
XR = 0.29	XR = 0.29	XR = 0.29
DR = 1.91	DR = 3.04	DR = 3.08
ETTA = 1.0	ETTA = 1.0	ETTA = 1.0
THETA = -	THETA = -	THETA = -

Card Type 11 (End of Data Indicator)

A blank card.

- 155mm (M107) Projectiles with 0.5-Inch Steel Plate Shield.



Average Outside Diameter	$D_i = 6.0$ inches
Average Casing Thickness	$X_i = 0.29$ inch
Height of Charge in Projectile	$H = 7.20$ inches
Density of Charge in Projectile (Comp B)	$\rho = 0.058$ lb/in ³

Density of Metal (Steel)

$$\rho = 0.283 \text{ lb/in}^3$$

Mass of Metal (Sidewalls)

$$77.5 \text{ lb} = 542,500.0 \text{ grains}$$

Input Table (A.2). 155mm Projectiles with shielding

Zone	Polar angle (deg)	FZ	FV	FM	XR	DR	n	θ (deg)	θ (rad)
1	70	0.07	0.732	0.07	0.68	4.09	1.0	20	0.35
2	80	1.00	0.862	0.18	0.68	5.45	1.0	10	0.17
3	90	1.00	0.967	0.377	0.68	6.09	1.0	0	0
4	100	1.00	0.967	0.377	0.82	6.00	1.0	10	0.17
5	110	0.87	0.862	0.18	1.36	6.54	1.0	20	0.35

Input Format - Example 2

Card Type 1

NCASE = 0

NPROJ = 1

Card Type 2

Title: 155mm (M107) Projectiles with 0.5-inch Steel Plate
Shield

Card Type 3

Type of Shield: 0.5-inch Steel Plate

Card Type 4

VC = 8800.00

DENC = 0.058

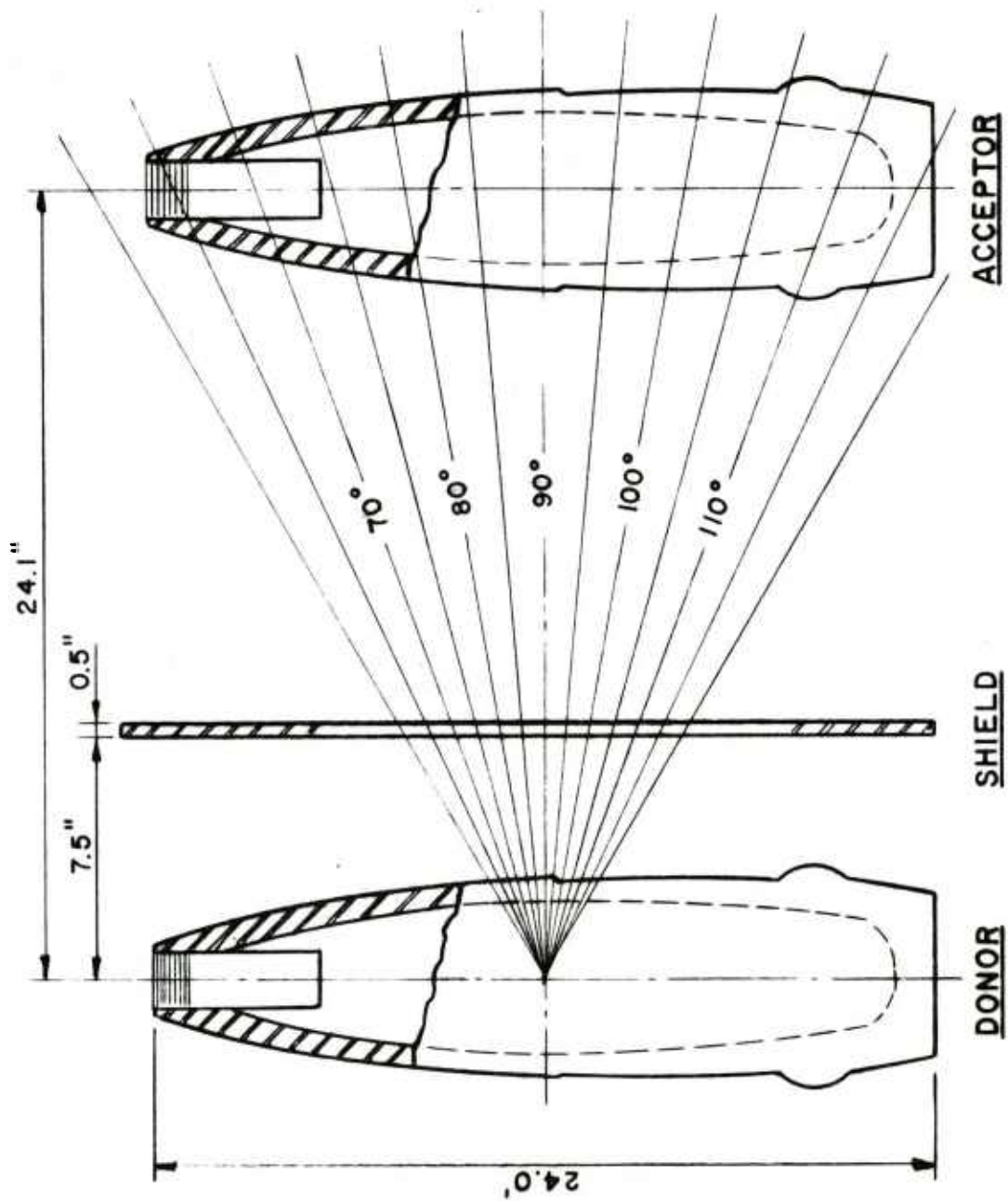


FIGURE A.2 155-mm (M107) projectiles with 0.5-inch steel plate.

DENM = 0.283

SK = 660.0

XM = 542500.13

XD = 0.68

DD = 6.09

Card Type 5

CO = 4500

SB = 2140

C1 = 0.8

FA = 0.5

FI = 0.2

PLATE = 0.5

Card Type 6 (From Table 1)

ALPHA = 0.889

BETTA = 0.945

GAMMA = 1.262

CONST = 6.390

LAMDA = 0.019

(Beta values are entered as positive values always)

Card Type 7 (From Table 2)

ALPH1 = 0.906

BETA1 = 0.963

GAMA1 = 1.280

CONT1 = 6.52

Card Type 8

SA = 0.61

CB = 0.283

XJ = 1820.74

Card Type 9

S1 = 7.5

S2 = 16.1

NZONE = 5

NMIS = 1

TWDTH = (blank)

Card Type 10 (From Input Table A.2). One card for each zone.

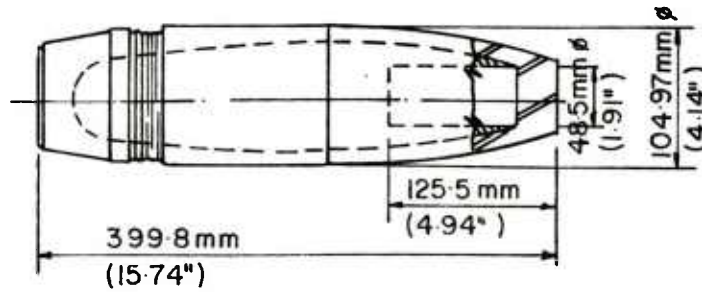
<u>1st Zone</u>	<u>2nd Zone</u>	<u>3rd Zone</u>
FZ = 0.07	FZ = 1.0	FZ = 1.0
FV = 0.732	FV = 0.862	FZ = 0.967
FM = 0.07	FM = 0.18	FM = 0.377
XR = 0.68	XR = 0.68	XR = 0.68
DR = 4.09	DR = 5.45	DR = 6.09
ETTA = 1.0	ETTA = 1.0	ETTA = 1.0
THETA = 0.35	THETA = 0.17	THETA = 0

<u>4th Zone</u>	<u>5th Zone</u>
FZ = 1.00	FZ = 0.87
FV = 0.967	FV = 0.862
FM = 0.377	FM = 0.18
XR = 0.82	XR = 1.36
DR = 6.0	DR = 6.54
ETTA = 1.0	ETTA = 1.0
THETA = 0.17	THETA = 0.35

Card Type 11 (End of Data Indicator)

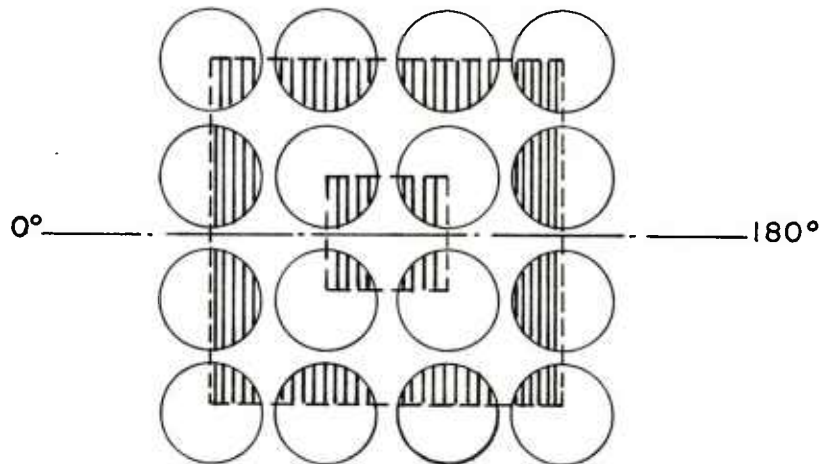
A blank card.

3. 105mm (M1) Projectiles - Sixteen (4 x 4) on Pallets



Average Outside Diameter	$D_i = 4.133$ inches
Average Casing Thickness	$X_i = 0.489$ inch
Height of Charge in Projectile	$H = 11.8$ inches
Density of Charge (Comp B)	$\rho_C = 0.058$ lb/in ³
Density of Metal (Steel)	$\rho_m = 0.283$ lb/in ³
Mass of Metal (Sidewalls)	$M = 25.5$ lb = 178,500.0 grains

Determination of C_A



For an azimuthal zone bounded by 0 and 180° line, the shaded regions show the portions of projectiles that are not involved in the fragment mass distribution. The equivalent weight of 5 projectiles is involved in fragment mass distribution:

$$\begin{aligned} C_A &= 5 \times \text{Wt. of single 105mm projectile (grains)} \\ &= 5 \times 178,500.0 \text{ grains} \\ &= 892,500.0 \text{ grains.} \end{aligned}$$

Determination of FZ:

For a separation of 360 inches, only the middle (90-degree) zone is involved.

$$FZ = 18H/\pi S = (18 \times 11.8)/\pi \times 360 = 0.188$$

Input Table

Table A.3. 105mm (M1) Projectiles

Zone	Polar angle (deg)	FZ	FV	FM	XR (in)	DR (in)	n
1	90	0.188	0.886	0.206	0.489	4.133	2.0

Separation distance = 360 inches

(See notes at bottom of Table A.1)

Input Format - Example 3

Card Type 1

NCASE = 0

NPROJ = 1

Card Type 2

Title: 105mm (M1) Projectiles Grouped 16 (4 x 4) on Pallet

Card Type 3

Type of Shield: None

Card Type 4

VC = 8800.00

DENC = 0.058

DENM = 0.283

SK = 660.0

XM = 892500.0

H = 11.8

XD = 0.489

DD = 4.133

Card Type 5

CO = 4500.0

SB = 2140.0

C1 = 0.8

FA = 0.5

FI = 0.2

PLATE = 0.0

Card Type 6

ALPHA = 0

BETTA = 0

GAMMA = 0

CONST = 0

LAMDA = 0

Card Type 7

ALPH1 = 0.0

BETA1 = 0.0

GAMA1 = 0.0

CONT1 = 0.0

Card Type 8

SA = 0.61

CB = 0.283

XJ = 1820.74

Card Type 9

S = 360.0

NZONE = 1

NMIS = 4

TWDTH = 19.53

Card Type 10 (From Input Table A.3). One card required for each zone.

1st Zone

FZ = 0.188

FV = 0.886

FM = 0.206

XR = 0.489

DR = 4.133

ETTA = 2.0

Card Type 11 (End of Data Indicator)

A blank card.

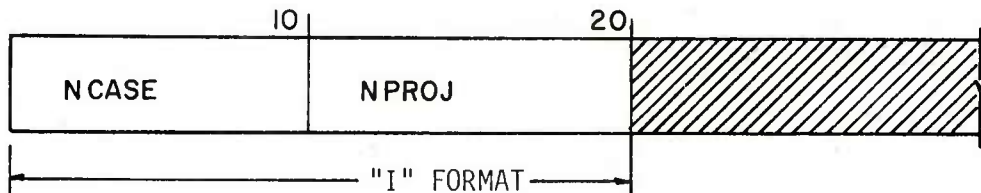
APPENDIX B INPUT FORMAT FOR COMPUTER PROGRAM

Introduction

This section presents the formats used for specifying the various input parameters. Each type of card is described below in terms of data format, definition and field locations. The numbers above the graphic representation of each card identify the last column in each data field of that card. The letters below designate the format for the data. In fields designated "I", the quantity entered must be right-adjusted to the last column in the field and cannot contain any decimal point. In the fields designated "F", a decimal point is required; however, the number can be located anywhere in the field. Fields designated "A" are alphanumeric fields and have to be left-adjusted, beginning at the first column of the field.

Data Cards

Card Type 1

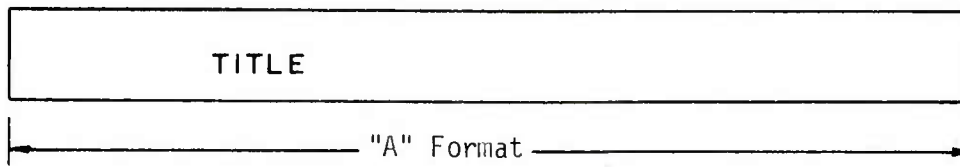


NCASE = 0 if high order detonation is the failure criterion

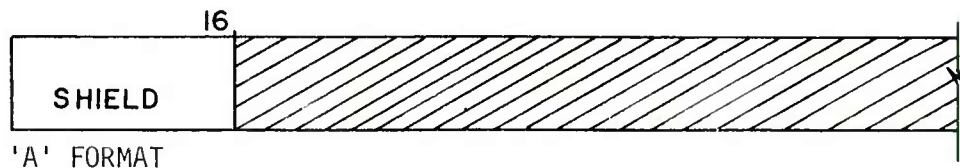
= 1 if perforation of the projectile casing is the failure criterion

NPROJ = number of times the program is to be used. If, for example, calculations are required for the 81mm and 155mm projectiles, then NPROJ = 2. Note that NPROJ does not mean the number of projectiles in a stack.

Card Type 2

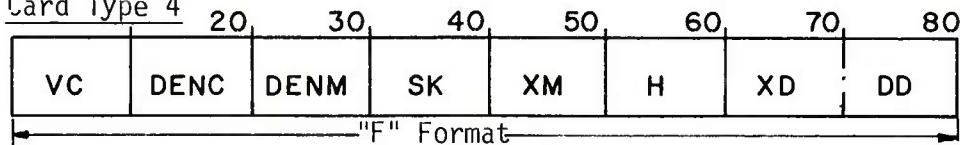


Card Type 3



If no shields are present, write "None". If this card is left out, when no shields are present, erroneous results will be obtained.

Card Type 4



VC = Gurney's constant (fps)

DENC = Density of charge (lb/in³)

DENM = Density of metal (lb/in³)

SK = Shape factor (grain/in³)

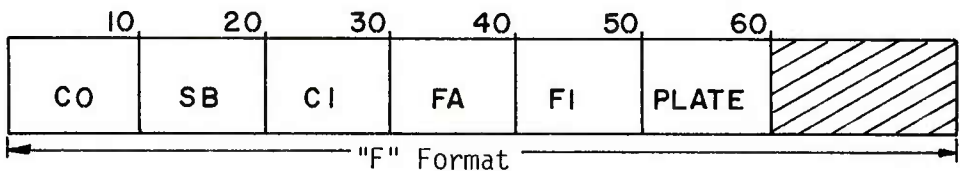
XM = Weight of metal (grain)

H = Height of charge in projectile (in)

XD = Average casing thickness (in) measured at middle of projectile

DD = Outside diameter of projectile (in) measured at middle of projectile also.

Card Type 5



CO = Average mass coefficient

SB = Sensitivity parameter

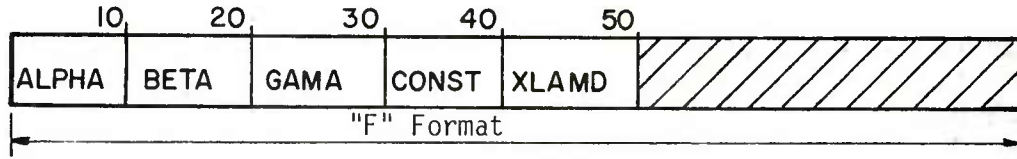
CI = Protection coefficient

FA = Area factor

FI = Impact factor

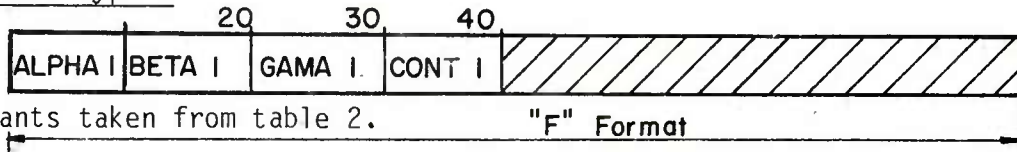
PLATE = Thickness of shield (in)

Card Type 6



These are constants obtained from table 1 of the report.

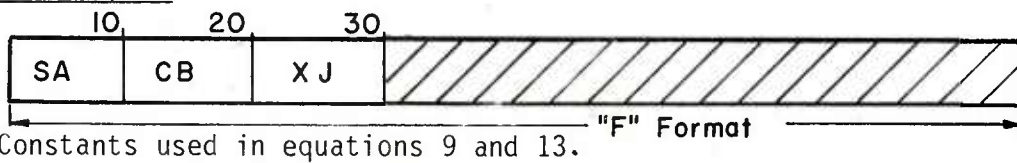
Card Type 7



Constants taken from table 2.

When no shields are present, the constants of card types 6 and 7 should contain zeros. An erroneous result will be obtained if these cards are left out entirely.

Card Type 8

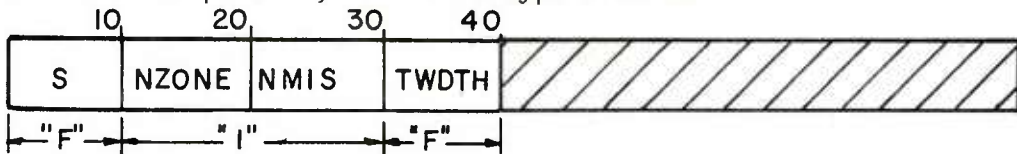


Constants used in equations 9 and 13.

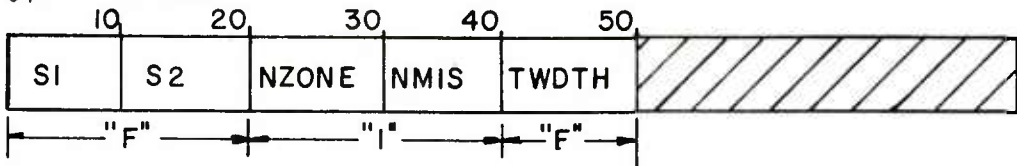
CB = B in equation 9.

SA = a)
XJ = J) equation 13

If no shields are present, then card type 9 would be



If shields exist between donor and acceptor projectiles, then card type 9 becomes



S = Center-to-center spacing between donor and acceptor projectiles (in) for no shields present.

S1 = distance from centerline of donor projectile to inner face of shield (in)

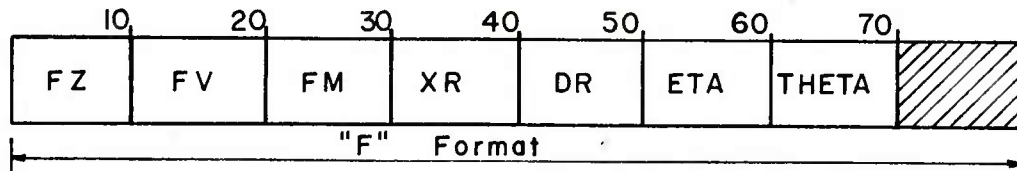
S2 = distance from outer face of plate to centerline of acceptor projectiles.

NZONE = Number of zones involved (see Sample Calculations).

NMIS = Number of projectiles in a row or column facing the donor source.

TWDTH = Length of the row or column of projectiles facing the donor source.

Card Type 10 (one required for each zone)



FZ, FV and FM are parameters defined in the report. XR and DR are the casing thickness and outside diameter in inches of acceptor projectile. The value of ETTA can be obtained from the second part of the report. THETA is the fragment impact angle of the face of the shield.

End of Data Indicator

A blank card is required at the end of data.

Program Listing

The PODS Program is written in FORTRAN language for the IBM 1130 Computer. Modifying it to run on any system should not be a difficult task.

The program is structured to predict the probability of detonation using either of the following:

1. Perforation of projectile casing as a failure criterion (NCASE > 0).
2. High order detonation as failure criterion (NCASE = 0).

Because of the dimensional constraints, only twenty 10-degree zones can be involved. This imposes a restriction to how close one projectile can be to another; however, the distances involved in ammunition facilities are within the limits.

As explained under "DESCRIPTION OF THE MODEL" in the main body of the report (on page 4), the computer program is presented below.

CARD COUNT

COLUMN	1	10	20	30	40	50	60	70	80
1	*****	*****	*****	*****	*****	*****	*****	*****	*****
2	*NAME	PODS							
3		REAL	HDG(20)						
4		COMMON	C1,CO,SB,SK,FA,FI						
5		COMMON	VO,Q,XMO,PLATE,XM						
6		COMMON	ALPHA,BETTA,GAMMA,XLAM,CONST						
7		COMMON	ALPHA1,BETA1,GAMA1,CONT1						
8		COMMON	SA,XJ,XMA						
9		READ(2,1001)	NCASE,NPROJ						
10	1001	FORMAT(4I10)							
11		DO 1 M=1,NPROJ							
12		READ(2,8)HDG							
13	8	FORMAT(20A4)							
14		READ(2,9)V1,V2,V3,V4							
15	9	FORMAT(4A4)							
16		READ(2,1000)VC,DENC,DENM,SK,XM,H,XD,DD							
17		READ(2,1000)CO,SB,C1,FA,FI,PLATE							
18		READ(2,1000)ALPHA,BETTA,GAMMA,CONST,XLAM							
19		READ(2,1000)ALPHA1,BETA1,GAMA1,CONT1							
20		READ(2,1000)SA,CB,XJ							
21	1000	FORMAT(8F10.5)							
22		WRITE(5,2000)							
23	2000	FORMAT(11,8X,'COMPUTATION OF PROBABILITY OF DETONATION AS FUNCTION OF DISTANCE AND SHIELDING')							
24		WRITE(5,1002)HDG							
25	1002	FORMAT(9X,20A4)							
26		WRITE(5,2001)							
27	2001	FORMAT(10,40X,16HPARAMETER VALUES)							
28		WRITE(5,2002)							
29	2002	FORMAT(35X,'*****')							
30		WRITE(5,2003)SK,CO							
31	2003	FORMAT(10,7X,30HSHAPE FACTOR K(GRAINS/CU.INS)=,F10.3,4X,23HAVERAG							
32		1E MASS COEFFICIENT K0=,F10.3)							
33		WRITE(5,2004)SB,C1							
34	2004	FORMAT(8X,25HSENSITIVITY PARAMETER B=,F10.3,9X,26HPROTECTION COEF							
35		1FICIENT K1=,F17.3)							
36		WRITE(5,2005)FA,FI							
37	2005	FORMAT(8X,15HAREA FACTOR FA=,F10.3,19X,23HIMPACT ANGLE FACTOR FI=,							
38		1F10.3)							
39		WRITE(5,2010)XJ,SA,CB							
40	2010	FORMAT(6X,24HCONSTANT J(SENSITIVITY)=,F10.3,2X,13HCONSTANT A(SENSY							
41		1)=,F10.3,2X,24HCONSTANT B(MOTT'S EQN.)=,F10.3)							
42		WRITE(5,2006)							
43	2006	FORMAT(10,40X,16HDONOR PROPERTIES)							
44		WRITE(5,2002)							
45		WRITE(5,2007)VC,DENC							
46	2007	FORMAT(10,7X,26HGURNEY'S CONSTANT VC(FPS)=,F10.2,8X,27HCHARGE DEN							
47		1SITY(LBS/CU.INS)=,F10.3)							
48		WRITE(5,2008)XM,DENM							
49	2008	FORMAT(8X,24HHEIGHT OF METAL(GRAINS)=,F10.3,10X,28HDENSITY OF META							
50		1L(LBS/CU.IN)=,F10.3)							
	*****	*****	*****	*****	*****	*****	*****	*****	*****
COLUMN	1	10	20	30	40	50	60	70	80

```

COLUMN 1      10      20      30      40      50      60      70      80
.....*.....*.....*.....*.....*.....*.....*.....*.....*
2009  FORMAT(8X,23HOUTSIDE DIAMETER(INS.)=,F10.3,11X,26HAVG.CASING THICK
      1NESS(INS)=,F10.3)
      WRITE(5,2011)
2011  FORMAT('0',32X,41HRECEPTOR PROJECTILE AND SHIELD PROPERTIES)
      WRITE(5,2012)
2012  FORMAT(32X,42H.....*.....*.....*.....*.....*.....*.....*.....*.....*
      WRITE(5,2013)H
2013  FORMAT(30X,36HHEIGHT OF CHARGE IN PROJECTILE(INS)=,F10.3)
      WRITE(5,2014)
2014  FORMAT('0',50X,10HTABLE ONE*)
      WRITE(5,2015)
2015  FORMAT('0',19X,1TARGET MATERIAL          CONSTANT          ALPHA
      1      BETTA          GAMMA          LAMDA')
2016  FORMAT(20X,44X,4X,E12.3,5X,E12.3,5X,E12.3,5X,E12.3,5X,E12.3)
      WRITE(5,2017)
2017  FORMAT('0',50X,10HTABLE TWO*)
      WRITE(5,2018)
2018  FORMAT('0',50X,10HTABLE TWO*)
      WRITE(5,2019)
2019  FORMAT('0',19X,1TARGET MATERIAL          CONSTANT          ALPHA
      1      BETTA          GAMMA')
2020  FORMAT(20X,44X,4X,E12.3,5X,E12.3,5X,E12.3,5X,E12.3,5X,E12.3)
      WRITE(5,2021)
2021  FORMAT('1',45X,7HRESULTS)
      WRITE(5,2022)
2022  FORMAT(45X,9H.....*.....*.....*.....*.....*.....*.....*.....*.....*
      WRITE(5,2023)Q
2023  FORMAT('0',29X,24HCHARGE-TO-METAL RATIO Q=,F10.5)
      WRITE(5,2024)V0
2024  FORMAT(30X,35HINITIAL VELOCITY OF FRAGMENTS(FPS)=,F10.3)
      IF (NCASE-1)100,101,101
      100 XMO=2*((DD*CO/V0)**2)
      GO TO 200
      101 XMB=((DD-2*XD)**0.3333)*(1+XD/(DD-2*XD))
      XMA=CR*(XD**0.8333)*XMR
      XMO=2*(XMA**2)*437.5
      200 WRITE(5,2025)XMO
2025  FORMAT(30X,30HAVERAGE FRAGMENT MASS(GRAINS)=,E12.3)
      IF (NCASE-1)103,104,104
      103 CALL ADLRP(FINAL,SX)
      DIST=SX
      GO TO 11
      104 CALL AWRPT(XFINA,SUX)
.....*.....*.....*.....*.....*.....*.....*.....*.....*
COLUMN 1      10      20      30      40      50      60      70      80
.....*.....*.....*.....*.....*.....*.....*.....*.....*

```

```

COLUMN 1      10      20      30      40      50      60      70      80
.....*.....*.....*.....*.....*.....*.....*.....*
101 DIST=SUJX
102 WRITE(5,3000)DIST,XFINA
103 GO TO 1
104
105 11 WRITE(5,3000)DIST,FINAL
106 3000 FORMAT('0',29X,17HFOR A DISTANCE OF,F8.2,39H(IN), THE PROBABILITY
107 1 OF DETONATION IS,E12.5)
108 1 CONTINUE
109 CALL EXIT
110 END
111 SUBROUTINE ADLRP(XPROB,DIXT)
112 DIMENSION FZ(20),FV(20),FM(20),XR(20),DR(20),ETTA(20),THETA(20)
113 COMMON C1,C0,SB,SK,FA,FI
114 COMMON V0,Q,XMO,PLATE,XM
115 COMMON ALPHA,BETTA,GAMMA,XLAMD,CONST
116 COMMON ALPHA1,BETA1,GAMA1,CONT1
117 COMMON SA,XJ,XMA
118 PI=3.1416
119 WRITE(5,4000)
120 4000 FORMAT('0',15X,'ZONE FZ FM CASE THICKNES
121 1S(IN) OUTER DIAMETER(IN)')
122 *****
123 *
124 * SUBROUTINE ADLRP CALCULATES THE PROBABILITY OF DETONATION AS FUNCTIONS
125 OF DISTANCE AND SHIELDING. HOWEVER, PERFORATION OF THE PROJECTILE
126 CASING IS NOT CONSIDERED A FAILURE CRITERION.HIGH ORDER DETONATION
127 IS THE FAILURE CRITERION CONSIDERED
128 *
129 *****
130 *
131 IF (PLATE=0.0)1,1,2
132 1 READ(2,1000)S,NZONE,NMIS,TWDT
133 1000 FORMAT(F10.5,2I10,F10.5)
134 DO 747 I=1,NZONE
135 747 READ(2,3001)FZ(I),FV(I),FM(I),XR(I),DR(I),ETTA(I),THETA(I)
136 3001 FORMAT(8F10.5)
137 XNBAR=0.0
138 DO 201 L=1,NZONE
139 XM1=XM0
140 NL=L
141 WRITE(5,4001)NL,FZ(L),FV(L),FM(L),XR(L),DR(L)
142 DO 202 K=1,200
143 FD=EXP(-0.0025*S*(1/(XM1**0.3333)))
144 V=V0*FV(L)*FD*ETTA(L)
145 Y=1-((SB**2)/(27*C1*XR(L)*(V**2)))*0.3333
146 XM3=SK*(PI/(4*FA)**1.5)*((SB*C1*XR(L)/(V*(Y**3))**2)
147 TIX=XM3-XM1
148 IF (ABS(TIX)-0.1)203,203,107
149 107 IF (K-100)108,108,119
150 108 XM1=XM3
.....*.....*.....*.....*.....*.....*.....*.....*
COLUMN 1      10      20      30      40      50      60      70      80

```

```

COLUMN 1 10 20 30 40 50 60 70 80
1 .....*.....*.....*.....*.....*.....*.....*.....*.....*
202 CONTINUE
GO TO 203
119 WRITE(5,1007)
GO TO 204
203 X4=XM*FM(L)/XM0
IF (NMIS-1) 330,330,331
330 FALFA=(DR(L)-2*XR(L))/(2*PI*S)
GO TO 332
331 FALFA=(TWDTH-NMIS*2*XR(L))/(2*PI*S)
332 SF=I*EXP(-(2*XM3/XM0)**0.5)
201 XNBAR=XNBAR+(XN*FALFA+FZ(L)*SF)
DIXT=S
XPROR=1-EXP(-XNBAR)
GO TO 222
2 READ(2,3002)S1,S2,MZONE,NMIS,TWDTH
3002 FORMAT(2F10.5,2I10,F10.5)
ST=S1+S2*PLATE
DO 707 I=1,MZONE
707 READ(2,3003)FZ(I),FV(I),FM(I),XR(I),DR(I),ETIA(I),THETA(I)
3003 FORMAT(8F10.5)
XNBAR=0.0
DO 401 L=1,MZONE
NL=L
WRITE(5,4001)NL,FZ(L),FV(L),FM(L),XR(L),DR(L)
Y41=X40
DO 17 K=1,1500
JK=K
FOD=EXP(-0.0025*S2*(1/(YM1**0.3333)))
COD=EXP(-0.0025*S1*(1/(YM1**0.3333)))
VIN=ETIA(L)*V0*FV(L)
VSP=VIN*COD
CAPPA=(YM1/SK)**0.6667
BINX=(10.0)**CONT1
BUNX=(PLATE*CAPPA)**ALPH1
DANX=(1/YM1**BETA1)
ANGX=(1/COS(THETA(L)))*GAMA1
XPVEL=BINX*BUNX*DANX*ANGX
DIFF=VSP-XPVEL
IF (DIFF-0.0)16,16,18
16 Y41=100000.
GO TO 206
18 CONTINUE
BIN=(10.0)**CONST
BUN=(PLATE*CAPPA)**ALPHA
DAN=(1/YM1**BETA)
ANG=(1/COS(THETA(L)))*GAMMA
VELO=VSP**XLAMD
TAME=BIN*BUN*DAN*ANG*VELO
VRI=VSP-TAME
VSR=VRI*FD
.....*.....*.....*.....*.....*.....*.....*.....*.....*
COLUMN 1 10 20 30 40 50 60 70 80

```

151
152
153
154
155
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COLUMN 1      10      20      30      40      50      60      70      80
*****
EAM=(4*FA/PI)**0.5
DAM=(YM1/SK)**0.3333
DIAM=EAM*DAM
VOTE=C1*XR(L)/DIAM
VUT=SB*(1/(DIAM**0.5))
VSRT=(1+VOTE)*VUT
BLOT=VSRT-VSR
IF (ABS(BLOT)-50.)206,206,3
3 IF (K-1000)4,4,109
4 YM1=XM0+JK*11.5
17 CONTINUE
GO TO 206
109 WRITE(5,1007)
GO TO 222
206 XY=XM*FM(L)/XM0
IF (NMIS-1)333,333,334
333 FALFX=(DR(L)-2*XR(L))/(2*PI*ST)
GO TO 335
334 FALFX=(TWDTH-NMIS*2*XR(L))/(2*PI*ST)
335 FS=FI*EXP(-(2*YM1/XM0)**0.5)
401 XMBAR=XMBAR+(XY*FALFX*FZ(L)*FS)
DIXT=ST
XPROB=1-EXP(-XMBAR)
1007 FORMAT('I',35)ITERATION PROCESS DOES NOT CONVERGE)
4001 FORMAT(17X,I2,4X,F6.3,4X,F6.3,4X,F6.3,8X,F10.3,17X,F10.3)
222 CONTINUE
RETURN
END
SUBROUTINE AWRPT(ZPROR,DUCT)
DIMENSION FZ(20),FV(20),FM(20),XR(20),DR(20),ETIA(20),THETA(20)
COMMON C1,C0,SB,SK,FA,FI
COMMON VO,Q,XMO,PLATE,XM
COMMON ALPHA,BETTA,GAMMA,XLAMD,CONST
COMMON ALPH1,BETA1,GAMA1,CONT1
COMMON SA,XJ,XMA
PI=3.1416
WRITE(5,4000)
4000 FORMAT('O',15X,'ZONE          FZ          FM          CASE THICKNES
1S(INCH)    OUTER DIAMETER(INCH)')
*****
C *
C *
C *
C SUBROUTINE AWRPT CALCULATES THE PROBABILITY OF DETONATION AS FUNCTIONS
C OF DISTANCE AND SHIELDING. IT CONSIDERES PERFORATION OF THE PROJECTILE
C CASING SUFFICIENT FOR FAILURE OF ENTIRE PROJECTILE.
C *
C *
C *****
IF (PLATE-0.0)1,1,2
1 READ(2,1000)SOT,LZONE,NMIS,TWDTH
*****
COLUMN 1      10      20      30      40      50      60      70      80

```

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COLUMN 1 10 20 30 40 50 60 70 80
.....*.....*.....*.....*.....*.....*.....*.....*.....*
1000 FORMAT(F10.5,2I10,F10.5)
DO 747 I=1,LZONE
747 READ(2,3001)FZ(I),FV(I),FM(I),XR(I),DR(I),ETTA(I),THETA(I)
3001 FORMAT(8F10.5)
XNBAR=0.0
DO 201 L=1,LZONE
TM3=XMO
NL=L
WRITE(5,4001)NL,FZ(L),FV(L),FM(L),XR(L),DR(L)
DO 7 K=1,2000
JK=K
FUD=EXP(-0.0025*SOT*(1/(TM3**0.3333)))
VK=VO*FV(L)*FUD*ETTA(L)
ABBA=VK/XJ
BIAM=(1.273*FA)**0.5
CIAM=(TM3/SK)**0.3333
DIAM=BIAM*CIAM
JAP=1+SA
EAM=C1*XR(L)*(1/(DIAM**JAP))
FAM=1/(DIAM**SA)
GAM=FAM+EAM
HAM=GAM-ABBA
IF (ABSCHAM)-0.05)203,203,107
107 IF (K-1500)108,108,119
108 TM3=XMO+.95*JK
7 CONTINUE
GO TO 203
119 WRITE(5,1007)
GO TO 201
203 XN=XM*FM(L)/XMO
IF (NMIS-1)330,330,331
330 FALFA=(DR(L)-2*XR(L))/(2*PI*SOT)
GO TO 332
331 FALFA=(TWDTH-NMIS*2*XR(L))/(2*PI*SOT)
332 SF=FI*EXP(-(TM3**0.5)/(XMA*20.9165))
201 XNBAR=XNBAR+(XN*FALFA*FZ(L)*SF)
DUCT=SOT
ZPROB=1-EXP(-XNBAR)
GO TO 222
C 2 READ(2,3002)S1,S2,MZONE
2 READ(2,3002)S1,S2,MZONE,NMIS,TWDTH
3002 FORMAT(2F10.5,2I10,F10.5)
SJ=S1+S2+PLATE
DO 707 I=1,MZONE
707 READ(2,3003)FZ(I),FV(I),FM(I),XR(I),DR(I),ETTA(I),THETA(I)
3003 FORMAT(8F10.5)
XNBAR=0.0
DO 401 L=1,MZONE
Y41=XMO
NL=L
.....*.....*.....*.....*.....*.....*.....*.....*.....*
COLUMN 1 10 20 30 40 50 60 70 80

```

CARD COUNT

COLUMN	1	10	20	30	40	50	60	70	80	CARD COUNT
	1********	301
		WRITE(5,4001)NL,FZ(L),FV(L),FM(L),XR(L),DR(L)								302
		DO 17 K=1,1500								303
		JK=K								304
		FOD=EXP(-0.0025*S2*(1/(YM1**0.3333)))								305
		COD=EXP(-0.0025*S1*(1/(YM1**0.3333)))								306
		VIN=ETTA(L)*VO*FV(L)								307
		VSP=VIN*COD								308
		CAPPA=(YM1/SK)**0.6667								309
		BINX=(10.0)**CONT1								310
		BUNX=(PLATE*CAPPA)**ALPH1								311
		DANX=(1/YM1**BETA1)								312
		ANGX=(1/COS(THETA(L)))*GAMA1								313
		XPVEL=BINX*BUNX*DANX*ANGX								314
		DIFF=VSP-XPVEL								315
		IF (DIFF-0.0)16,16,18								316
		16 YM1=100000.								317
		GO TO 206								318
		18 CONTINUE								319
		BIN=(10.0)**CONST								320
		BUN=(PLATE*CAPPA)**ALPHA								321
		DAN=(1/YM1**BETA)								322
		ANG=(1/COS(THETA(L)))*GAMMA								323
		VELO=VSP**XLAMD								324
		TAME=BIN*BUN*DAN*ANG*VELO								325
		VRI=VSP-TAME								326
		VSR=VRI*FOD								327
		EAM=(4*FA/PI)**0.5								328
		DAM=(YM1/SK)**0.3333								329
		DIAM=EAM*DAM								330
		VOTE=C1*XR(L)/DIAM								331
		VUT=SB*(1/(DIAM**0.5))								332
		VSRT=(1+VOTE)*VUT								333
		BLOT=VSRT-VSR								334
		IF (ABS(BLOT)-50.)206,206,3								335
		3 IF (K-1000)4,4,109								336
		4 YM1=XMO*JK*11.5								337
		17 CONTINUE								338
		GO TO 206								339
		109 WRITE(5,1007)								340
		GO TO 222								341
		206 XY=XM*FM(L)/XMO								342
		IF (NMIS-1)333,333,334								343
		333 FALFX=(DR(L)-2*XR(L))/(2*PI*SIJ)								344
		GO TO 335								345
		334 FALFX=(TWDTH-NMIS*2*XR(L))/(2*PI*SIJ)								346
		335 FS=FI*EXP(-(YM1**0.5)/(XMA*20.9165))								347
		401 XMBAR=XMBAR+(XY*FALFX+FZ(L)*FS)								348
		DUCT=SIJ								349
		ZPROR=1-EXP(-XMBAR)								350
		1007 FORMAT('1',35)ITERATION PROCESS DOES NOT CONVERGE)								
COLUMN	1********	

CARD COUNT

COLUMN	1	10	20	30	40	50	60	70	80
*********
4001	FORMAT(17X,12,4X,F6.3,4X,F6.3,4X,F6.3,8X,F10.3,17X,F10.3)								
222	CONTINUE								
	RETURN								
	END								

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COMPUTATION OF PROBABILITY OF DETONATION AS FUNCTIONS OF DISTANCE AND SHIELDING
 81MM PROJECTILES - NO SHIELDS - H.O. DETONATION

PARAMETER VALUES

SHAPE FACTOR K(GRAINS/CU.INS)= 660.000 AVERAGE MASS COEFFICIENT K0= 4500.000 0.800
 SENSITIVITY PARAMETER B= 2140.000 PROTECTION COEFFICIENT K1= 0.200
 AREA FACTOR FA= 0.500 IMPACT ANGLE FACTOR FI= 0.283
 CONSTANT J(SENSITIVITY)= 1820.740 CONSTANT A(SENSY)= 0.610 CONSTANT B(MOTT'S EQN.)= 0.283

DONOR PROPERTIES

GURNEY'S CONSTANT VC(FPS)= 8800.00 CHARGE DENSITY(LBS/CU.INS)= 0.058
 WEIGHT OF METAL(GRAINS)= 35000.007 DENSITY OF METAL(LBS/CU.IN)= 0.283
 OUTSIDE DIAMETER(INS.)= 3.000 AVG.CASING THICKNESS(INS)= 0.290

RECEPTOR PROJECTILE AND SHIELD PROPERTIES

 HEIGHT OF CHARGE IN PROJECTILE(INS)= 7.200

TABLE ONE*

TARGET MATERIAL NO SHIELDS	CONSTANT 0.000E 00	ALPHA 0.000E 00	BETTA 0.000E 00	GAMMA 0.00000E 00	LAMDA 0.000E 00
-------------------------------	-----------------------	--------------------	--------------------	----------------------	--------------------

* NOTE THAT ANY NEGATIVE SIGNS THAT SHOULD APPEAR IN THE TABLE HAVE BEEN/OR SHOULD BE TAKEN CARE OF IN THE PROGRAM.

TABLE TWO*

TARGET MATERIAL NO SHIELDS	CONSTANT 0.000E 00	ALPHA 0.000E 00	BETTA 0.000E 00	GAMMA 0.000E 00
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* NOTE THAT ANY NEGATIVE SIGNS THAT SHOULD APPEAR IN THE TABLE HAVE BEEN/OR SHOULD BE TAKEN CARE OF IN THE PROGRAM.

RESULTS

CHARGE-TO-METAL RATIO Q= 0.38140
INITIAL VELOCITY OF FRAGMENTS(FPS)= 4982.725
AVERAGE FRAGMENT MASS(GRAINS)= 0.145E 02

ZONE	FZ	FV	FM	CASE THICKNESS(INS)	OUTER DIAMETER(INS)
1	0.570	0.862	0.183	0.290	1.910
2	1.000	0.967	0.377	0.290	3.040
3	0.430	0.967	0.377	0.290	3.080

FOR A DISTANCE OF 21.08(INS), THE PROBABILITY OF DETONATION IS 0.61140E-01

COMPUTATION OF PROBABILITY OF DETONATION AS FUNCTIONS OF DISTANCE AND SHIELDING
155MM PROJECTILES WITH 0.5IN ST'L PLT. H.O. DETON.

PARAMETER VALUES

SHAPE FACTOR K(GRAINS/CU.INS)= 660.000 AVERAGE MASS COEFFICIENT K0= 4500.000 0.800
SENSITIVITY PARAMETER B= 2140.000 PROTECTION COEFFICIENT K1= 0.200 0.283
AREA FACTOR FA= 0.500 IMPACT ANGLE FACTOR FI= 0.610 CONSTANT R(MOTT'S EQN.)= 0.283
CONSTANT J(SENSITIVITY)= 1820.740 CONSTANT A(SENSY)= 0.610

DONOR PROPERTIES

GURNEY'S CONSTANT VC(FPS)= 8800.00 CHARGE DENSITY(LBS/CU.INS)= 0.058
WEIGHT OF METAL(GRAINS)=542500.126 DENSITY OF METAL(LBS/CU.IN)= 0.283
OUTSIDE DIAMETER(INS.)= 6.090 AVG-CASING THICKNESS(INS)= 0.680

RECEPTOR PROJECTILE AND SHIELD PROPERTIES

HEIGHT OF CHARGE IN PROJECTILE(INS)= 17.600

TABLE ONE*

TARGET MATERIAL ST'L PLT(0.5INS)	CONSTANT 0.639E 01	ALPHA 0.889E 00	BETTA 0.945E 00	GAMMA 0.12620E 01	LAMDA 0.190E-01
-------------------------------------	-----------------------	--------------------	--------------------	----------------------	--------------------

* NOTE THAT ANY NEGATIVE SIGNS THAT SHOULD APPEAR IN THE TABLE HAVE BEEN/OR SHOULD BE TAKEN CARE OF IN THE PROGRAM.

TABLE TWO*

TARGET MATERIAL ST'L PLT(0.5INS)	CONSTANT 0.652E 01	ALPHA 0.906E 00	BETTA 0.963E 00	GAMMA 0.128E 01
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* NOTE THAT ANY NEGATIVE SIGNS THAT SHOULD APPEAR IN THE TABLE HAVE BEEN/OR SHOULD BE TAKEN CARE OF IN THE PROGRAM.

RESULTS

CHARGE-TO-METAL RATIO = 0.31160
INITIAL VELOCITY OF FRAGMENTS(FPS)= 4569.200
AVERAGE FRAGMENT MASS(GRAINS)= 0.719E 02

ZONE	FZ	FV	FW	CASE THICKNESS(INS)	OUTER DIAMETER(INS)
1	0.070	0.732	0.070	0.680	4.090
2	1.000	0.862	0.180	0.580	5.450
3	1.000	0.967	0.377	0.680	6.090
4	1.000	0.967	0.377	0.820	6.000
5	0.870	0.862	0.180	1.360	6.540

FOR A DISTANCE OF 24.10(INS), THE PROBABILITY OF DETONATION IS 0.00000E 00

COMPUTATION OF PROBABILITY OF DETONATION AS FUNCTIONS OF DISTANCE AND SHIELDING
CALCULATION OF PROBABILITY FOR A GROUP OF 16 105MM (M1) PROJECTILES TEST CALCS.

PARAMETER VALUES

SHAPE FACTOR K(GRAINS/CU.INS)= 660.000 AVERAGE MASS COEFFICIENT K0= 4500.000
SENSITIVITY PARAMETER B= 2140.000 PROTECTION COEFFICIENT K1= 0.800
AREA FACTOR FA= 0.500 IMPACT ANGLE FACTOR FI= 0.200
CONSTANT J(SENSITIVITY)= 1820.740 CONSTANT A(SENSEY)= 0.610 CONSTANT B(MOTT'S EQN.)= 0.283

DONOR PROPERTIES

GURNEY'S CONSTANT VC(FPS)= 8800.00 CHARGE DENSITY(LBS/CU.INS)= 0.058
WEIGHT OF METAL(GRAINS)=892500.126 DENSITY OF METAL(LBS/CU.INS)= 0.283
OUTSIDE DIAMETER(INS.)= 4.133 AVG.CASING THICKNESS(INS)= 0.489

RECEPTOR PROJECTILE AND SHIELD PROPERTIES

HEIGHT OF CHARGE IN PROJECTILE(INS)= 11.800

TABLE ONE*

TARGET MATERIAL	CONSTANT	ALPHA	BETTA	GAMMA	LAMDA
NONE	0.000E 00	0.000E 00	0.000E 00	0.00000E 00	0.000E 00

* NOTE THAT ANY NEGATIVE SIGNS THAT SHOULD APPEAR IN THE TABLE HAVE BEEN/OR SHOULD BE TAKEN CARE OF IN THE PROGRAM.

TABLE TWO*

TARGET MATERIAL	CONSTANT	ALPHA	BETTA	GAMMA
NONE	0.000E 00	0.000E 00	0.000E 00	0.000E 00

* NOTE THAT ANY NEGATIVE SIGNS THAT SHOULD APPEAR IN THE TABLE HAVE BEEN/OR SHOULD BE TAKEN CARE OF IN THE PROGRAM.

RESULTS

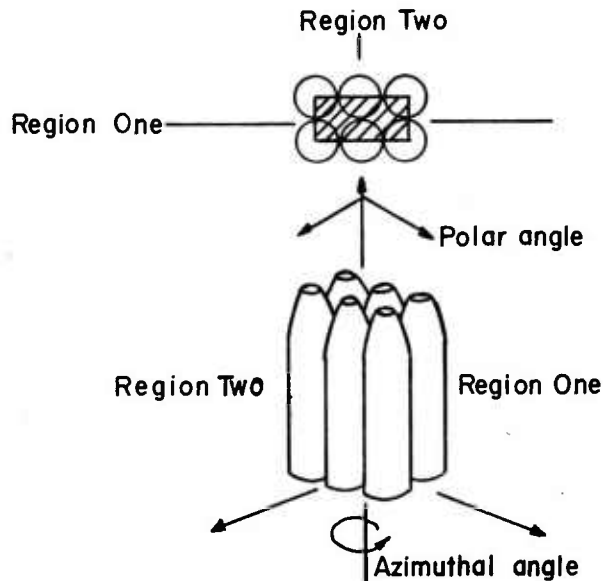
CHARGE-TO-METAL RATIO = 0.28621
INITIAL VELOCITY OF FRAGMENTS(FPS)= 4403.375
AVERAGE FRAGMENT MASS(GRAINS)= 0.356E 02

ZONE	FZ	FV	FW	CASE THICKNESS(INS)	OUTER DIAMETER(INS)
1	0.337	0.886	0.206	0.439	4.133

FOR A DISTANCE OF 360.00(INS), THE PROBABILITY OF DETONATION IS 0.20645E 00

APPENDIX C DIFFERENT PROJECTILE CONFIGURATIONS

Rotational symmetry at the source of explosion cannot be assumed when a group of projectiles are in a configuration other than the "square matrix" arrangement. Assuming that all required information is available, the following steps would help in predicting the probability of detonation for grouped projectiles:



Figures 1&2

1. Determine the fragment mass distribution in both Regions 1 and 2 (fig. 1).
2. Determine the fragment velocities in the same regions also. These distributions are taken as functions of the azimuthal angle only.
3. Determine the same distributions listed in 1. and 2. above as functions of the polar angle (fig. 2).
4. Resolve the distributions for each region to obtain parameters FV and FM which are now expressed as functions of two angles:

$$FV = f_1(\phi, \theta)$$

$$FM = f_2(\phi, \theta)$$

where ϕ and θ are polar and azimuthal angles, respectively.

5. Determine C_A , the fraction of metal weight involved in fragment distribution.
6. With these modifications, the overall model can now be used to predict probability of detonation for a group of projectiles in any configuration.

It should be noted that determination of the distributions mentioned in 1. and 2. above can only be achieved through field tests.

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